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MOTION SIMULATOR STUDY OF LONGITUDINAL STABILITY REQUIREMENTS FOR LARGE DELTA WING TRANSPORT AIRPLANES DURING APPROACH AND LANDING WITH STABILITY AUGMENTATION SYSTEMS FAILED

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SUMMARY

A ground-based simulator investigation using the Ames Flight Simulator for Advanced Aircraft (FSAA) was conducted by a joint NASA[1]/FAA[2]/CAL[3] research team in preparation for and correlation with an in-flight simulator program using the CAL Total In-Flight Simulator (TIFS). The objective of these studies was to define minimum acceptable levels of static longitudinal stability for landing approach following stability augmentation systems failures. The airworthiness authorities are presently attempting to establish the requirements for civil transports with only the backup flight control system operating.

Using a baseline configuration representative of a large delta wing transport, 20 different configurations, many representing negative static margins, were assessed by three research test pilots in 33 hours of piloted operation. Verification of the baseline model to be used in the TIFS experiment was provided by computed and piloted comparisons with a well-validated reference airplane simulation. Pilot comments and ratings are included, as well as preliminary tracking performance and workload data.

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1. National Aeronautics and Space Administration
2. Federal Aviation Administration
3. Cornell Aeronautical Laboratory, Inc.

Results of this investigation led to the selection of time to double amplitude of angle-of-attack response (T_{2_α}) as the best measure of the instability. Such a criterion may prove to be one acceptable means of establishing requirements for the emergency landing condition. Conservative analysis of the data indicate T_{2_α} should be greater than six seconds.

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NOTATION

a_z	normal acceleration, ft/sec^2 or g
b	wing span, ft
c_r,c	wing reference chord, ft
C_D	drag coefficient, $\frac{\text{drag force}}{q_o S}$
C_L	lift coefficient, $\frac{\text{lift force}}{q_o S}$
C_m	pitching moment coefficient, $\frac{\text{pitching moment}}{q_o Sc}$
d	ground effect height parameter, $d = (h_w + 17.85)/41.93$
F_c	column force, lb
F(d)	ground effect height factor
g	acceleration due to gravity, 32.2 ft/sec^2
h	altitude, ft
h_w	wheel height, ft
I_{xx}	rolling moment of inertia, slug-ft^2
I_{yy}	pitching moment of inertia, slug-ft^2
I_{zz}	yawing moment of inertia, slug-ft^2
I_{xz}	product of inertia, slug-ft^2
L	aerodynamic lift force, lb
M	aerodynamic pitching moment, lb-ft
p	roll angular velocity (right roll, positive), rad/sec or deg/sec
q	pitch angular velocity (ANU, positive), rad/sec or deg/sec
q_o	dynamic pressure, lb/sq ft.
r	yaw angular velocity, (nose right, positive), rad/sec or deg/sec
S	wing reference area, ft.^{2}
T	thrust, lb
T_r	thrust required, lb
T_2	time to double amplitude, sec
T_2( )	time to double amplitude based on the parameter ( ), sec

V	airspeed, ft/sec. or knots
V_{app}	approach speed, knots
V_c	calibrated airspeed, knots
W	airplane weight, lb
α	angle of attack, rad or deg
β	angle of sideslip, rad or deg
γ	flight-path angle, rad or deg
δ_a	aileron deflection, deg
δ_c	column deflection, in
δ_e	elevon deflection, deg
$\delta_{P_{STAB}}$	roll damper command, deg
δ_r	rudder deflection, deg
δ_{TH}	throttle deflection, deg
δ_w	control wheel deflection, deg
$\Delta(\ )$	deviation from reference
ε_{GS}	error from ILS glide slope, deg
ε_{LOC}	error from ILS localizer, deg
ζ_d	Dutch roll damping ratio
θ	airplane pitch attitude, rad or deg
ϕ	roll angle, rad or deg
ψ	heading angle, rad or deg
ω_{n_d}	Dutch roll undamped natural frequency, rad/sec
t_r	roll time constant (response), sec
$(\dot{\ })$	derivative with respect to time, $\frac{d}{dt}$
$d\gamma/dV$	flight-path stability, deg/knots

$$C_{m_\alpha} = \frac{\partial C_m}{\partial \alpha} \qquad C_{m_{C_L}} = \frac{\partial C_m}{\partial C_L}$$

$$C_{m_{\dot{\alpha}}} = \frac{\partial C_m}{\partial \frac{\dot{\alpha} c}{V}} \qquad C_{m_q} = \frac{\partial C_m}{\partial \frac{qc}{V}}$$

$$C_{m_{\delta_e}} = \frac{\partial C_m}{\partial \delta_e} \qquad C_{L_\alpha} = \frac{\partial C_L}{\partial \alpha}$$

ADI	attitude director indicator
AFSC	Air Force Systems Command
ANU,AND	airplane nose up, airplane nose down
CAL	Cornell Aeronautical Laboratory, Inc.
CG	center of gravity
FAA	Federal Aviation Administration
FSAA	Flight Simulator for Advanced Aircraft
GE	ground effect
HSI	horizontal situation indicator
IFR	instrument flight rules
ILS	instrument landing system
LWD	left wing down
NA	not applicable
PIO	pilot induced oscillation
PR	pilot rating (Cooper-Harper scale)
RMS	root mean square
SAS	stability augmentation system
SST	supersonic transport
NASA	National Aeronautics and Space Administration
TD	touch down
TIFS	Total In-Flight Simulator
VFR	visual flight rules

INTRODUCTION

Because of the aft movement of center of pressure as an aircraft goes supersonic, the CG for supersonic cruise is often located near or behind the subsonic neutral point to minimize the drag. Therefore, many advanced configurations of aircraft designed for supersonic cruise must rely on stability augmentation (for example: pitch damping and automatic trimmers) to achieve the desired longitudinal trim and stability characteristics at subsonic speeds (references 1 and 2). In the event of systems failures (i.e., SAS or fuel transfer systems) such an aircraft could be required to complete the approach and landing in a statically unstable condition. Existing handling qualities data indicate that a moderate level of static instability is controllable and may be tolerable for the emergency condition.

The airworthiness authorities are presently attempting to define civil transport requirements for these emergency conditions, and in this particular study, the minimum certifiable level of static longitudinal stability with only the backup flight control system operating. To assist in this effort a piloted simulator study was conducted as part of an on-going cooperative NASA/FAA airworthiness standards research program at the Ames Research Center.

This simulator study was conducted to provide information in preparation for a related study (sponsored by FAA Systems Research and Development Service and administered by AFSC Flight Dynamics Laboratory) by Cornell Aeronautical Laboratory, Inc. (CAL) using the CAL Total In-Flight Simulator (TIFS). The Ames ground-based Flight Simulator for Advanced Aircraft (FSAA) was used by a joint NASA/FAA/CAL research team to verify the TIFS baseline configuration by comparison with the reference airplane simulation. The reference airplane was a well-validated simulation of a large delta wing transport airplane. These simulations were used to refine the scope of the TIFS experiment and define the evaluation tasks. Pilot evaluations and ratings were then obtained for 20 different evaluation configurations, many representing negative static margins, for correlation of FSAA and TIFS findings. This report presents a documentation of the configurations tested on the FSAA and preliminary results, with a minimum of data interpretation.

The authors acknowledge the contributions of Cornell Aeronautical Laboratory Inc., and in particular, Messrs. Robert P. Harper, Jr. and R. Wasserman who participated directly in these tests.

EQUIPMENT

Simulator

The study was conducted using the Flight Simulator for Advanced Aircraft (FSAA) at NASA Ames Research Center (figure 1). This simulator has six degrees of motion freedom, and is described in references 3 and 4 (only five degrees of motion freedom were operable for the study reported in reference 3). Details of the simulator pertinent to this study are summarized below.

Cockpit. - The interior of the three-man FSAA cab was representative of a transport aircraft flight deck equipped for flight test. The panel instruments and controller mechanical design and location were representative of SST category airplanes. The lateral controller was of the "ram's-horn" shape, and was powered by a hydraulic control loader, as were column and rudder controllers. The mechanical characteristics of the flight controls are presented in table I.

The panel instruments provided appropriate sensitivities for an airplane of this category. The attitude director indicator (ADI), shown in figure 2, had a pitch scale of 1.8 deg/mm. The airspeed indicator had a scale of 300 knots per revolution of the dial face. Annunciator lights below the glare shield indicated individual main and nose-gear touchdown.

Motion system. - The six-degrees-of-freedom motion system of the FSAA is distinguished by its extensive lateral travel of ±40 ft. The motion axis of primary interest for these tests, however, was the vertical, which had ±4.0 ft of usable travel. This provided a capability for effectively simulating motion resulting from a turbulent flight environment and the initial onset of maneuvering accelerations but does not permit large motions which would result from sustained normal accelerations.

The D.C. drive signals to the servo motors were high-pass filtered to constrain motion within the allowable limits for each axis. Discussions of these filters and the effectiveness of FSAA motions on the piloted task are contained in reference 3 and in appendix A of reference 4.

Briefly summarized, the FSAA motion logic was configured as follows: Second order high-pass "wash-out" filters were generally applied to the drive signals. For longitudinal, an additional first-order time constant was required. A damping ratio of 0.7 was used for all modes, and the break-frequencies were 0.5 rad/sec for lateral, roll, and yaw accelerations, and 1.4 rad/sec for vertical, pitch, and longitudinal accelerations.

The roll-lateral and the pitch-longitudinal modes used the residual-tilt technique of washing-in cab angular attitude to provide a steady-state component of linear acceleration. These sustained linear accelerations were provided at full scale for lateral, and one-half scale for longitudinal. Scale factors for all other commanded accelerations were 1.0 except for roll and vertical, which were 0.5.

The pitch drive had a malfunction which persisted for the duration of the investigation: the velocity-command servo had a dead zone of about ±1.5 to 2.0 deg/sec within which no motion occured.

Several weeks after concluding the study, a brief investigation was made to determine the effects of the pitch motion malfunction. Several TIFS configurations were re-evaluated by two of the program pilots, plus a third pilot, with the pitch motion malfunction reproduced and with a pitch motion operating properly. No significant differences were apparent, and the pilot ratings from all three pilots were consistent with previous results.

<u>Visual system.</u> - The pilot and copilot were each provided a 21 in. color television monitor (diagonal measure) mounted in the windshield with a viewing field of 38° vertically and 46° horizontally, with unity magnification. The pilot's monitor had a collimating lens to place the image at an infinite distance.

The landing scene was the closed-circuit TV image of a model airport with surrounding terrain, as viewed by the computer-commanded servo-driven TV camera. Model scale was 1:600 and provided a runway 8000 ft long and 150 ft wide.

Sound system. - A sound generator simulated jet engine noise which was proportional to thrust, and aerodynamic noise which was proportional to aircraft speed. These sounds were introduced by speakers on each side of the cabin. In addition to adding realism, a primary benefit of this sound environment was to mask the noise of the simulator motion drive systems.

TEST PROCEDURE

TIFS Experiment Design

The test matrix for the TIFS experiment, designed by CAL, consisted of 20 evaluation configurations and is shown in table II. The baseline model approximated a large delta-wing jet transport, shown in figure 3. Simplified equations for the airborne TIFS analog computer were developed by CAL from a well-validated delta-wing reference airplane simulation available at Ames. The development of these equations and supporting data are contained in references 5 through 9.

As indicated in table II, the primary variable was static longitudinal stability C_{m_α}; also treated as variables were curvature of the Cm vs α function, the flight-path stability $(d\gamma/dV)$, and the longitudinal damping $(Cm_q + Cm_{\dot{\alpha}})$. Five levels of static stability were studied, including one very stable level and four unstable levels. Because the characteristic response of statically unstable aircraft is usually dominated by an aperiodic divergent root, time to double amplitude (T_2) was selected as a primary parameter. The three most unstable levels were designed to correspond to times to double amplitude of 8 sec, 4 sec, and 2 seconds, as predicted by a linear analysis root approximation method. (Measurement of T_2 is discussed in the Results and Discussion section.)

Three levels of $C_m(\alpha)$ curvature were studied: (1) linear C_{m_α}, (2) curvature approximately baseline, and (3) twice the curvature of (2). The effects of flight-path stability were assessed for two drag conditions: the reference airplane drag curve provided a range of $d\gamma/dV$ on the "back side" of the drag curve, and a modified drag curve provided zero $d\gamma/dV$. Two levels of damping were studied, the baseline value and an increased damping case (5 x baseline). When damping was increased, C_{m_α} was made more unstable to retain the same T_2 values.

Ames Simulation Tests

Math modeling and verification. - Modeling of the TIFS configurations for the Ames tests was accomplished by using the existing delta-wing transport simulation as a foundation, replacing the C_L and C_m buildup equations by the appropriate TIFS equations, and placing modifying factors in the existing drag equation for the zero $d\gamma/dV$ cases. The TIFS C_L and C_m equations were:

$$C_L = -.177 + .0606\alpha + .00548\,\frac{qc}{V} + .00575\,\frac{\dot{\alpha}c}{V} + .01184\,\delta_e + F(d)\left[.0210 + .00262\,\delta_e - .0007\,\frac{qc}{V}\right]$$

$$C_m = C_{m_0} + C_{m_1}\alpha + C_{m_2}\alpha^2 + C_{m_3}\alpha^3 - .00342\,\delta_e - C_{m_q}\frac{qc}{V} - C_{m_{\dot{\alpha}}}\frac{\dot{\alpha}c}{V} + F(d)\left[.0059 + \Delta C_{m_{\alpha_{GE}}}\alpha + \Delta C_{m_{\delta e_{GE}}}\delta_e\right]$$

where F(d) is shown in figure 4 and the pitching moment coefficients for the various configurations are given in table III.

Stability augmentation was off in all axes and autothrottle was off for the TIFS configuration evaluations.

Verification of the TIFS baseline model was performed by computer checks and by piloted comparisons of the TIFS baseline configuration with the "foundation" simulation, hereafter called the "reference airplane".

Computer checks consisted of:

(1) free air "one-g" trim values of α, δ_e and thrust

(2) thrust required vs. speed

(3) C_m vs. α in free-air and in full ground effect for two c.g. conditions

(4) Incremental α and δ_e required for trim at various ground heights

(5) Dynamic response to elevator steps and pulses.

Piloted checks consisted of subjective comparisons of the two simulations in the IFR approach and VFR landing task. (Changeover between the TIFS baseline and the reference airplane required only a few seconds.)

Additional computer documentation included verifying that the modified drag equation provided zero $d\gamma/dV$ and dynamic response checks of all TIFS configurations for graphical determination of the actual T_2 values.

Piloted evaluations. - Approximately 33 hours of piloted operation were logged, with the initial 4.5 hours devoted to checkout, familiarization, and task definition, and the remaining 28.5 hours to the actual configuration evaluations.

Three research test pilots representing CAL, FAA, and NASA conducted the evaluations. Each configuration evaluation consisted of four runs of differing tasks, designated A, B, C, and D, described below.

Task A Air work, included pitch response checks, speed excursions, windup turns, etc.

Task B Normal approach

Task C Crosswind (15-knot) approach with a glideslope error correction. Approximately one-dot glideslope error correction was required at about 800 ft. altitude.

Task D Offset localizer approach with moderate (3.0 ft/sec RMS) turbulence. 200-ft localizer lateral offset was apparent at VFR breakout.

Repeat runs were allowed when requested by the pilot. Tasks B, C, and D were IFR approaches and VFR landings from the initial conditions shown in figure 5. As shown, the pilot was required to capture localizer from a 30° intercept angle, capture the 3-deg. glidescope, track the ILS until breakout at 300-ft. altitude, then perform a VFR landing. A low level of turbulence (0.5 ft/sec RMS) was present in all the evaluation runs except Task D, which included moderate turbulence (3.0 ft/sec RMS).

Pilots gave extensive pilot comments using, as a guide, a trial CAL questionnaire being developed for the flight tests. Configurations were given a pilot rating based on the handling qualities scale shown in table IV (from reference 10) and a turbulence rating based on the scale shown in table V. Two important pilot-rating ground rules agreed upon during the initial preflight briefing were:

a) What is the pilot population being considered?-----
A select group of airline pilots subjected to training requirements which would provide some familiarity with failure-mode instability effects.

b) Single-pilot or 2-pilot (crew) task?-----
Use single-pilot active control task whereby pilot handles all primary controls including thrust-levers, but assuming a second crew member is present to handle communications, fire warnings, other distractions, etc.

The evaluating pilot was not told which configuration was being evaluated. The order (sequencing) of configurations was pseudo-random, except that the very divergent cases ($T_2 \cong 2.0$ sec) were never given as the first configuration in any test session. Configurations 1, 13, and 20 were included as possible "good airplane" reference points because they have well-separated stable short-period and phugoid modes. The augmented "reference airplane" was also used for a "good airplane" calibration point, especially for the first few runs in the initial test sessions.

RESULTS AND DISCUSSION

Results of the study are divided into three sections. The first section discusses validation of the TIFS baseline math model and documents the responses of the various test configurations. The second and third sections present results from the piloted evaluations; the second contains the subjective assessments and pilot ratings and the third contains the quantitative data from these runs.

Baseline Validation and Test Configuration Responses

Validation of TIFS baseline model. - Validation of the TIFS baseline model was performed by comparison with the "reference airplane" simulation.

Total drag, lift, and pitching moment values were confirmed by level-flight one-g trim checks at the test gross weight (231,483 lbs.) and nominal approach speed (V_c = 160 kts) in free air and in full ground effect. Trim values of thrust, angle of attack, and elevator deflection are shown in table IV. Thrust and angle of attack values match within 2%; one-degree mismatch in absolute elevator angle was considered insignificant for the intended tests. The incremental changes in all three quantities due to ground effect match within 6%.

Static longitudinal stability was checked by trimming the airplane for level flight, then varying angle of attack by one-degree increments and recording the total C_m for each angle of attack. Figure 6(a) shows the results of these checks in free air and in full ground effect. (The trim value of C_m represents that necessary to offset the pitching moment due to thrust.) A further check (figure 6(b)) was made at a condition corresponding to a 2-percent-c_r aft shift in CG to provide confidence in the in-ground-effect static stability modeling as discussed in appendix A. As shown, there was good agreement.

Pitch dynamic response checks are shown in figures 7 and 8. Figure 7 shows the response to a one-degree elevator step in the nose-up direction, resulting in good agreement. Figure 8 shows the response to an elevator pulse disturbance (-5 degrees for 0.2 second), plotted on semi-log paper to facilitate measurement of the effect of the aperiodic divergent root. Measured T_2 values were 4.0 seconds and 3.7 seconds for the reference airplane and for TIFS baseline, respectively, a difference that was not discernible to the pilots.

The variation of ground effect with height was checked by examining the incremental angle of attack and incremental elevator to trim, as shown in figure 9. Incremental angle of attack matched well with the reference airplane. Incremental elevator matched well at touchdown, but more elevator was required for the TIFS baseline at intermediate heights. This resulted from the use of a common height factor curve (figure 4) for lift and pitching moment, proposed by CAL on the basis of computing equipment constraints aboard the TIFS airplane. Comparative piloted assessments of the flare and touchdown task indicated that the reference airplane was slightly easier to flare, giving the impression of "more cushion" or "smoother" ground effect. However, the pilots felt the difference was not large enough to warrant the added complexity of separate height factors, and the decision was made initially to use the common curve for both lift and pitching moment. Much later in the test program, during evaluation of a very stable configuration which required nearly twice the incremental elevator to flare as the baseline, one pilot complained of an unnatural nose down pitching moment between 200 and 100 feet altitude on two successive runs. Immediately following these runs, a repeat run was made utilizing separate height factors for C_L and C_m. The objectionable trim change was no longer apparent. On the basis of this experience, it was recommended that the TIFS airplane tests utilize separate ground effect height factors for lift and pitching moment.

Thrust required for level flight was recorded at various speeds about the nominal approach speed. Flight path stability, $d\gamma/dV$, was then estimated from the relationship:

$$\frac{d\gamma}{dV} \cong \frac{d(T_r/W)}{dV} \times 57.3 \qquad \text{(deg/kt)}$$

As shown in figure 10(a), the TIFS baseline thrust requirements matched that of the reference airplane, and it was confirmed that the drag equation modifications produced $d\gamma/dV$ very near zero. $\frac{d\gamma}{dV}$ was found to be a function of stability level as indicated in figure 10(b); estimated values of $d\gamma/dV$ for the various evaluation configurations are presented later in the report.

Since lateral-directional characteristics were not of primary concern, the TIFS simplified lateral directional equations (reference 8) were not evaluated. For the FSAA study, the lateral-directional characteristics of the unaugmented reference airplane were used for all configurations. Responses to an aileron step and a rudder doublet are shown in figures 11(a) and 11(b) respectively. Table VII summarizes the measured lateral-directional characteristics and compares them with military flying qualities minimum requirements for transport category airplanes (references 11). As indicated, these characteristics satisfied not only requirements for system-failed operation (Level 2), but also those for normal operation (Level 1). However the lateral-directional characteristics were degraded by excessively high rudder breakout forces (see pilot's comments in table X).

Response of various test configurations. - Because most of the configurations being evaluated were longitudinally unstable, considerable attention was given to defining how they appear to the pilot, and to defining the best way of measuring and categorizing the divergent response. Figures 12 and 13 show the response of the primary piloting parameters (pitch attitude, rate of climb or descent, airspeed, and, indirectly, angle of attack) to an elevator step, indicative of a small control input or an out-of-trim condition, and to an elevator impulse, indicative of a small disturbance. In studying the responses shown in these figures, it is helpful to refer back to the test matrix of table II.

Figure 12 compares the responses of a stable configuration (no. 1) and an unstable one (no. 5) to a one-degree elevator step. The stable case seeks a new trim point at a slightly increased angle of attack, although a long-period phugoid oscillation is also evident. The unstable case continues to diverge at an increasing rate, illustrating the effect of the aperiodic divergent root.

Figure 13 compares the responses of the various test configurations to an elevator pulse (-5 degrees for 0.2 second duration). Figure 13(a) compares the various linear C_{m_α} configurations 1 through 5. Configuration 1 returns to trim. Little difference is apparent to the pilot between configurations 2 and 3 until approximately 15 seconds after the pulse, where the rate of climb is decreasing for no. 2 and increasing in no. 3. The difference in response between cases 3, 4, and 5 is quite marked, however.

Figure 13(b) illustrates the effect of varying the curvature of the $C_m(\alpha)$ function by comparing configurations 4, 7, and 9. Figure 13(c) also shows the effect of the non-linear $C_m(\alpha)$ by comparing responses in the noseup and nose-down directions for configuration 9. Because of the decreasing stability as α is increased, the nose-up disturbance results in a more rapid divergence than the nose-down disturbance.

Figure 13(d) shows the effect of the drag characteristics by comparing configuration 4 ("backside" of drag curve) with configuration 11 ($d\gamma/dV \cong 0$). As shown here, the effect in response to a disturbance is quite subtle, but its effect on pilot workload during maneuvering proved more significant than is suggested here.

Figure 13(e) shows the effect of the increased pitch damping by comparing configuration 9 with configuration 18, which had 5 times the damping ($C_{mq} + C_{m_{\dot{\alpha}}}$) as no. 9. These cases showed the same time to double amplitude T_{2_α}. As the pilots described it, configuration 18 was insidious because it hesitated for a short time before diverging (also see figures 14(b) and 14(d)).

Measurement of the divergence was done by plotting the elevator pulse response of angle of attack vs time on semilog paper and measuring the slope. Angle of attack was used because it was least contaminated by the phugoid mode. All the measured T_2 values are based on a nose-up response, because it was the more critical. The work sheets from which the T_2 values were determined are shown in figure 14. The slope was measured within the approximate region of $t = 5$ to 15 seconds (for $\Delta\alpha$ amplitudes of approximately 0.5 to 2.0 deg). Additional T_2 work sheets for pitch attitude and calibrated airspeed are presented in figures 15 and 16 respectively, and measured T_{2_α}, T_{2_θ}, and T_{2_V} values are compared in table VIII. As shown, trends are consistent but the numerical values differ depending on the parameter selected. T_{2_θ} values are the largest (slowest divergence) and match the predicted values best: T_{2_V} values are the smallest. Correlation with pilot ratings appeared slightly better using T_{2_α}.

Table IX presents a summary of the various test configurations, containing measured T_{2_α}, $d\gamma/dV$, and trim values of thrust, angle of attack, and elevator angle in free air and in full ground effect.

Subjective Assessments and Pilot Ratings

Pilot ratings and associated comments for the various test configurations have been summarized in table X. More complete pilot comments have been included as Appendix B. Repeat evaluations were conducted for some cases and are shown separately. Evaluations were not repeated on the same day, and the pilot was not informed that a repeat was being conducted.

The stable configurations (1, 13, 20) were included for reference purposes, with C_{m_α} selected to provide well-separated short-period and phugoid modes. However, these cases represented unrealistically stable cases for the tailless delta class of aircraft. (C_{m_α} corresponded to CG positioned at about 40% C_r, while normal landing CG range for the reference airplane was 51.5% to 53% C_r.) Therefore, in some instances, these very stable cases were downgraded by the pilots because of sluggish response and high control forces. To remedy these complaints, configurations 1 and 13 were modified by increasing $C_{m_{\delta_e}}$ by 40%. On the basis of these evaluations, shown at the bottom of Table X, it was recommended that the increased level of $C_{m_{\delta_e}}$ be used with the stable configurations in the TIFS airplane tests.

The pilot ratings were plotted versus the measured time to double amplitude, divided into three categories:

(1) Normal damping and "backside" of drag curve; configurations 1 through 9, shown in figure 17(a).

(2) normal damping and $d\gamma/dV = 0$; configurations 10 through 12, shown in figure 17(b),

(3) high damping and "backside" of drag curve; configurations 13 through 19, shown in figure 17(c).

In figure 17, symbol shape identified the pilot, and symbol shading indicates the degree of non-linearity in the $C_m(\alpha)$ function. The shaded zone indicates the region of pilot ratings and is based largely on the data of figures 17(b) and (c). It is included in figure 17(a) because it appears to encompass most of the points for pilots B & C for this case also. Pilot A appeared to be less tolerant of high divergence rates than pilots B & C.

The data indicate that some instability is acceptable for abnormal operating conditions; values of T_{2_α} greater than approximately 6 seconds are indicated to be tolerable. For the high damping or $d\gamma/dV=0$ cases, slightly lower values of T_{2_α} ($\approx$5 sec) might be tolerated.

Considerable scatter exists in the non-linear $C_m(\alpha)$ data. This may be due to inadequate exposure to this characteristic. If an approach was well controlled and α excursions kept small, the pilot would not realize the non-linearity existed. It was recommended that, for the TIFS airplane tests, a 15-knot speed reduction be required prior to capturing the glideslope to increase exposure to this characteristic.

It must be recognized that some reservations remain with regard to the above pilot ratings. Research pilots with extensive experience in unstable aircraft were attempting to extrapolate to the situation of an airline pilot coping with an emergency. For more definitive conclusions it appears advisable that additional evaluations be conducted using airline pilots and a task which requires immediate pilot accommodation from a "good" airplane to a severely degraded one.

Quantitative Data

Data acquisition was provided by the following means: Strip chart recorders provided 48 channels of information in time history form; these included control position, thrust, glideslope error, localizer error, airplane position, airplane attitudes, translational accelerations, angular rates, angles of attack and sideslip. A magnetic tape digital recording of this information was also made. The recording sample rate was 22 samples per second. A digital printout of significant parameters followed each simulated landing; a sample is shown in table XI. Pilot comments were recorded on a voice actuated cassette tape recorder.

Control characteristics and pilot workload data. - Data were obtained during piloted operation of the FSAA to evaluate the 20 airplane configurations of the TIFS experiment. Selected representative data runs flown by pilot B (configurations 1, 4, 5, 11, 15, and the augmented reference airplane) are presented in figures 18 through 28 for discussion in this section.

As described in the Test Procedure, pilot evaluations were begun with handling qualities tests (Task A) during air work prior to making approaches. The evaluation tasks for the landing approach flight phase were tasks B, C, and D, described previously. The initial point for beginning each task was at the same altitude and location outside the outer marker, as illustrated in figure 5. Figures 18, 19, and 20 are time histories of the IFR portion of these three tasks while the VFR portion, including landing, is shown in figures 21, 22, and 23. These data were taken from strip chart recordings of control actions and of the flight parameters being controlled during an evaluation of TIFS configuration 15 (T_{2_α} = 3.6 sec). Figure 18 shows a normal approach, Task B, with localizer and glideslope captured at about 40 seconds after the run was initiated. The glideslope and localizer beam displacement error signals are shown as the two traces on the second channel from the top of the figures. A negative error indicates that the airplane is low relative to the glideslope centerline and is left of the localizer centerline. The glideslope and localizer indications were presented to the pilot on the ADI and HSI respectively. The flight director was not used with the ADI.

Task C is illustrated in figure 19, the glideslope error correction occurring at about 660 feet altitude. An increase in pilot workload due to increased turbulence of Task D over Task B is apparent when comparing column position and throttle position traces of figure 20 with those of figure 18.

A normal VFR landing is shown in figure 21 where a slight tendency to over-flare leading to a subsequent float may be noted prior to touchdown. The increased difficulty of the cross-wind landing flare and runway alignment is evident from the column and wheel position traces of figure 22. Right-wing-down roll command and nose-left rudder were required to counter the drift due to the 15 knot crosswind. (The roll damper command trace is not meaningful since all dampers were selected "off" for all TIFS configurations.) Figure 23 illustrates a VFR landing following an approach with recovery from a localizer offset 200 feet to the left of the runway centerline. Overflare again resulted in floating prior to touchdown, not a surprising result with the imprecise pitch control present in such unstable configurations.

Familiarization and verification work in the FSAA was facilitated by having the reference airplane simulation readily available for repeated orientation. This gave the evaluation pilots an opportunity to review a familiar simulation with good handling qualities associated with operational stability augmentation systems. Figure 24 illustrates the control characteristics of the reference airplane during a Task D approach and landing. Good flight-path control is evident, small column inputs and few changes in total thrust being required. Airspeed, rate of climb, and ILS beam displacements were well controlled to desired values.

Figure 25 shows the same task accomplished with the TIFS configuration 1 (stable). The apparent workload increase is due to pitch response of the more stable airplane to turbulence. One pilot commented, "It is too stable" and rated the effect of turbulence as causing minor deterioration of task performance. Excessive aft control column was needed to flare for landing. This was caused by elevator effectiveness being set at a level which was not well matched to the selected level of static stability.

For TIFS configuration 4 (T_{2_α} = 3.6 sec), figure 26, there were significant differences in the numerical rating given by each pilot. There was agreement that the primary problem was a lack of precision in pitch attitude control. The worst rating was given by pilot A because of the pitch control difficulty and the intense concentration required during the crosswind landing task (time history of this task is not shown.) It is clear that continuous control on the part of the pilot was required. Large control inputs were required, and the airplane appeared "sluggish" with pitch rates continuing after control input was removed. These characteristics caused a tendency to PIO, which was aggravated by introducing turbulence. The ability to control airplane pitch attitude through a "tight control loop" was lost. The high rate of divergence was not readily apparent to the pilot as such during his control task.

Airspeed control was poor (fig 26).Many thrust changes were needed to maintain airspeed near the desired approach value. Being off trim airspeed, or having the elevator trimmed to the wrong position, increased the control task since inputs were then required about some elevated force level. Thus, being as near the correct trim conditions as possible was very important.

Control characteristics of configuration 5 (T_{2_α} = 2.0 sec) are shown in figure 27. This was one of the most divergent configurations in the test matrix. The effect of "backside" operation is evident by the large speed variations and excessive thrust activity. Pilot workload was intense, and the pilots reported being physically tired after an approach and landing. Although the run was successfully completed, it is apparent that control would have been lost during flight if only brief inattention were caused by any additional pilot workload requirements. The configuration was rated uncontrollable.

The effect of $d\gamma/dV$ on pilot workload during Task D is shown by comparison of figure 26 with figure 28. Figure 26, TIFS configuration 4 ($d\gamma/dV$ = 0.11), differs from figure 28, TIFS configuration 11 ($d\gamma/dV \approx 0$), only in the level of flight-path stability. The control task and pilot technique is the same for both runs. A marked decrease in pilot workload required to control airspeed, pitch attitude, and rate of sink is apparent for configuration 11.

Large thrust changes were required during the configuration 4 run and even larger thrust changes were required during the configuration 5 run, figure 27. For the "backside" operation with the highly divergent configuration 5, pilots commented unanimously that control would be lost during some portion of required operation. The use of an autothrottle might not provide all the assistance required if pitching moments due to thrust changes were significant and required countering column inputs.

Flight-path tracking performance. - An indication of the pilots' ability to maintain the desired approach path is presented for several TIFS configurations in figure 29. This figure presents airplane lateral deviation, airspeed, and rate of sink plotted versus wheel height at a point 3,000 feet short of the runway threshold. The wheel height should be 196 feet at this point. The elapsed time required to reach this point after VFR breakout was approximately 7 seconds. All of these data are taken from normal approaches to the runway, Task B.

The magnitude of the flight-path error from an on-beam centerline condition is indicated by the dashed line rectangles on the figures. The rectangles represent a closed area wherein the localizer instrument error is not greater than 1/2 dot ($\epsilon_{LOC} \leq 0.625°$) and the glideslope instrument error is not greater than 2 dots ($\epsilon_{G.S.} \leq 0.7°$). The reference approach speed, V_{APP}, is 160 knots calibrated airspeed. At this speed, a rate of sink of 14.2 feet/second will maintain a three degree descending flight path.

The TIFS configurations for which data are presented are grouped to show tracking performance related to the main variables of the test matrix. Figure 29a includes configurations 1 through 5 for which static stability was varied from a stable airplane (configuration 1) to an unstable airplane with a two second aperiodic divergence (configuration 5). Figure 29(b) includes configurations 3, 6, and 8 for which curvature of the $C_m(\alpha)$

function was varied. Configurations 3 through 5 and 10 through 12 are grouped in figure 29(c) to show differences due to flight-path stability for the most unstable cases. The variation in airspeed for configurations 10 through 12 (for which $d\gamma/dV \cong 0$) is small compared to configurations 3 through 5 ($d\gamma/dV$ varies from .11 to .10). Figure 29(d) includes configurations 3 through 5 and 14 through 16. Pitch damping for configurations 14 through 16 is increased to five times that for configurations 3 through 5.

Touchdown dispersion. - Digital data describing the conditions at main gear touchdown were obtained from the digital printout of the landing runs (sample shown in table XI). These data are presented as a basis for evaluating performance during the simulated landing tasks. Roll attitude, airspeed, and rate of sink versus pitch attitude are shown in figure 30. Distance from runway threshold and main gear track angle versus lateral deviation from runway certerline are shown in figure 31.

The touchdown performance data does not correlate with the pilot rating data. In many cases the pilot would have decided to "go around" rather than attempt the landing in an actual emergency situation. It is possible that all landings could be completed from the runway threshold "window" and still be rated as unacceptable during the approach.

The dashed lines in figure 30 represent the approximate pitch and roll attitude at which the tail skid, outboard engine exhaust nozzle or wing tip would first contact the ground with the main gears or gear compressed. The width of the simulated runway was 150 feet.

Adequacy of simulation. The pilots considered the FSAA simulation to be very good for the evaluation of these longitudinally unstable configurations. There was enough motion to provide a measure of realism and anxiety, and the workloads were representative of similar flight tasks.

CONCLUDING REMARKS

A ground-based simulator investigation was accomplished in preparation for a program using the USAF/CAL Total In-Flight Simulator. In addition to providing numerous specific recommendations for the flight program, preliminary estimates of the minimum acceptable levels of static longitudinal stability were determined using pilot-rating data as the primary defining factor. Based on T_{2_α} (semilog plots) as a criterion, the conservative data limits from the three pilots indicate T_{2_α} should be greater than six seconds.

Flight path stability $d\gamma/dV$ was demonstrated to be a significant factor. The pilots commented that "backside" operations compounded whatever problems already existed. An autothrottle might not be an adequate solution if large adverse pitching moments due to thrust existed with an unstable airplane. When $d\gamma/dV$ (nominally about .11 deg/kt for this class of aircraft) was reduced to zero, workload was significantly reduced and some reduction in the acceptable limit of T_{2_α} was indicated.

Increased damping ($C_{m_q} + C_{m_{\dot{\alpha}}}$) appeared to reduce the minimum acceptable T_2, although pilots commented that this created an insidious delay in divergence. Nonlinearity of $C_m(\alpha)$ also appears significant, but the evaluation task was considered inadequate to expose the total effects of this characteristic.

The pilots considered the FSAA simulator to be quite good for the TIFS evaluations, and that the workloads were representative of similar flight tasks.

Additional confirmation evaluations were recommended using airline pilots and a task which requires immediate pilot accommodation from a "good" airplane to a severely-degraded one.

APPENDIX A

MODELING OF PITCHING MOMENT IN GROUND EFFECT

In the computer program, the ground effect pitching moment coefficient was represented by the equation

$$\left(\Delta C_m\right)_{GE} = F(d)\left[\Delta C_{m_{o_{GE}}} + \Delta C_{m_{\alpha_{GE}}}\alpha + \Delta C_{m_{\delta_{e_{GE}}}}\delta_e\right]$$

The term $\Delta C_{m_{\alpha_{GE}}}$ was assumed to vary as the free-air C_{m_α}, thus providing a ground effect representative of that likely to accompany the test free-air C_{m_α}. This value was computed as follows:

$$\Delta C_{m_{\alpha_{GE}}} = \left(\Delta C_{m_{\alpha_{GE}}}\right)\text{baseline} + \Delta C_{m_{C_L}} \cdot \Delta C_{L_{\alpha_{GE}}}$$

$$= -.0023 + .0255\Delta C_{m_{C_L}}$$

where

$$\Delta C_{m_{C_L}} = \left(C_{m_{\alpha_{test}}} - C_{m_{\alpha_{baseline}}}\right)/C_{L_\alpha}$$

$$= \left(C_{m_{\alpha test}} - .00037\right)/.0606$$

and

$$C_{m_{\alpha test}} = C_{m_1} + 2\ C_{m_2} \cdot \alpha + 3\ C_{m_3} \cdot \alpha^2$$

thus

$$\Delta C_{m_{\alpha_{GE}}} = -.0023 + \frac{.0255}{.0606}\left(C_{m_{\alpha_{test}}} - .00037\right)$$

Validity of this procedure was verified by comparison of $C_m(\alpha)$ in ground effect at two c.g.'s for the reference airplane and for the TIFS baseline with an equivalent C_{m_α} shift as shown in figure 6.

APPENDIX B

PILOT COMMENTS FROM FSAA/TIFS CORRELATION STUDIES

TIFS Configuration #1 (Stable)

Pilot A - First Evaluation. The airplane is basically stiff in pitch and elevator forces are fairly heavy. The airplane response is predictable but sluggish in the sense that the airplane likes my inputs enough that when I am trying to make something happen in a hurry, I detect a lag and have to put in additional corrective inputs because my predicter did not work perfectly. Trim is well defined and easy to achieve. Behavior off-trim air speed is predictable but the steady force that you are required to carry interferes with your ability to do an accurate and precise job. Elevator control motion is objectionably large. A very objectionable feature is the large elevator control needed to handle the ground effect during flare and touchdown. The heavy elevator forces give a somewhat inert feeling in pitch on the glide-slope.

Maneuvering control in turning flight is where the heavy forces and large control motions that are required to maneuver come into play and are objectionable. All of the IFR tasks are somewhat affected by these heavy forces but performance capability was still fair to good. Airspeed has a tendency to wander from trim speed and requires attention, but the fact that the attitude control is reasonably precise makes it easy to devote that kind of attention to air speed. I will rate this a 5 - C.

Pilot A - Second Evaluation. ($Cm_{\delta e} = -.007$). Pitch attitude control is probably the best I have seen. Airspeed control is beautiful. I tend to have a great deal of difficulty with the lateral-directional characteristics. The problem seems to be where the ground effect noses me down. I was able to do the crosswind landing, but not as well as I would liked to have done. Everything seems to be a fairly high workload in terms of the forces required to do the job but certainly an acceptable set of characteristics. I will rate it a 4 -- but skip the turbulence rating.

Pilot B - The airplane has strong static stability. It is too stable. Five knots off the airspeed creates pitch problems because it is hunting a new trim position, evidently because the airspeed errors cause more problems in pitch control than the airplane itself. The control input required in the elevator is not gross. The gradient on the elevator is a little high to get the desired response out of the machine. I noticed a sloppiness of about one degree when I am trying to hold a pitch attitude but I think it is the fact that the airspeed is off and I am being sloppy about a new trim point along with the gradient of the elevator. It needs more Δ g capability.

The lateral-directional characteristics are relatively sloppy and cause some tracking problems because you get into a lateral-directional oscillation. You think you have the heading held and you see that the yawing oscillation has induced a roll problem which causes a heading change. I may have been inducing some of this because I didn't always get the rudder I wanted. With the high breakout force, it is hard to get one degree to two degrees of rudder. Airspeed control with power is no problem. Turbulence didn't amount to much, except causing me to bounce up and down. I will rate this a 5 - C.

Pilot C - First Evaluation - This has a very strong sense of stability and high longitudinal stick forces. There is not as much damping in pitch as you might like. It is pretty springy in pitch. If you find a trim point with trim and power, then it is very easy to fly an approach and make corrections. The off-speed case produces a large out-of-trim force and you can feel it and that is good and bad.

The airplane generally tended to maintain speed independent of the fact that you were on the back side. It was difficult unless you really got off speed and started looking at some things to see that you really were on the back side. The drag speed stability was completely masked.

There is plenty of maneuvering capability and plenty of "g" capability. Large corrections were easily made. The hardest correction to make was one below the glide slope trying to come up on it, adding power and getting a nose-up pitching moment, nose-up trim change, and with all the stability you have, you carry a lot of stick force to hold it from wanting to pitch higher. I will rate this a 3 - A or B.

Pilot C - Second Evaluation - It is a stable airplane on the back side of the drag curve. There is very low pitch damping apparent in the cockpit which is like having divergence but it does not have one, of course. It springs back. The combination of the low control power and the short period oscillation causes it to be bobbing about and there is a PIO tendency. The transfer of speed errors induced by drag speed instability into pitching moments which overpower longitudinal control power cause very high stick forces to be applied in order to maintain the ILS glide slope. Rough air really aggravates the PIO. I will rate this a 5 - E.

TIFS Configuration #2 (T_{2_α} = 8.4 sec)

Pilot A - Airplane will continue to respond in pitch to an elevator input until you put a control input in to stop it. Pitch attitude required a lot of attention but it was predictable and I was able to make corrections fairly well. It was somewhat difficult to maintain air speed. I made power corrections, but not large enough.

Lateral-directional control inputs cause excessive, or undesirable, longitudinal aircraft motions. Rudder breakout was somewhat objectionable. All other control system characteristics were adequate. Performance during IFR portion was directly related to amount of time spent on pitch attitude. The most objectionable characteristics were the attention that attitude control requires and the tendency of airspeed to depart where it was supposed to be. Turbulence did not bring out any particular difficulties. I will rate it a 6 - C.

Pilot B - That was light to moderate instability and it looks like it was in the bucket on the power required curve. Pitch control is still sensitive but much less of a problem than some of the other configurations. It diverges up and down in pitch at a moderate rate. There was a much tighter loop on the cross-check. The crosswind was no problem. Turbulence was not as big a factor. I will rate it a 5 - D.

Pilot C - This configuration was significantly better than the previous one (#6). Back side operation was about the same. Speed control was poor as I could only manage to hold it within ± 10 knots most of the time. Within this range there is probably a three degree or four degree attitude change required to stay on the same flight path. There was a significant improvement in attitude stability. The airplane seemed a little harder to get pushed off into a pitch rate but the pitch rates did seem to be induced by rough air disturbances.

The airplane is slow and sluggish and it is difficult to fly pitch attitude precisely. Even with the largest control inputs that are gotten, you cannot push that nose up and down at a very high rate. It does not respond quickly enough and it maintains pitch rates that are induced by pilot inputs or disturbances. It does not stop when you release the forces. I do not have the controllability problem that I had with the previous one though. I will rate it a 6 - D.

TIFS Configuration #3 (T_{2_α} = 5.5 sec)

Pilot A - This is not a very good configuration. Pitch slowly diverges. It is a very high workload task to keep pitch attitude where you want it. I appeared to have a PIO going in pitch at times. Trim is not well defined. If you are off trim airspeed, the airplane behavior is unstable and it tends to depart further in attitude and airspeed. Elevator authority is good and I would like to have better precision.

Use of the ailerons tends to a induce pitching velocity in one direction or the other; probably because of inadvertent elevator inputs. Also, you have to add power properly and in phase with bank angle or else your airspeed starts to diverge. As you make these throttle corrections, you induce pitching moments which you must correct with elevator inputs. Airspeed diverges rapidly and you must keep a lot of attention on it. There is plenty of thrust to keep airspeed under control. The combination of the pitch attitude characteristics and the tendency of the airspeed to depart increase your workload to the point where you are not devoting enough attention to the other things that are important. As a result, the performance in the other tasks is degraded. I will rate this a 7 - D.

Comments for the same configuration with elevator gearing reduced to one half of the original value. This reduced the inadvertent pitch inputs from initiating attitude changes that produced real big errors by the time I got back to looking at them again. I think maybe I went a little too far in the gearing change because I had to do a lot of trimming to compensate for the pitching moments due to power. I would rate this a 6.

Pilot B - It is an unstable configuration. It drifts away rather than zooming off. The precision of the control is not what I would desire. It is sloppy, but controllable. The pitch will continue to diverge unless you stop it. It requires more monitoring of pitch attitude and airspeed. I have to increase my rate of cross-check between the two. Airspeed changes induce pitch changes. Also, had some lateral-directional inputs when I didn't want them but it may just have been lack of bank angle control. When you went VFR, there was an order of magnitude decrease in task. Turbulence increased the difficulty in scanning the instruments. I will rate this a 6 - D.

Pilot C - First Evaluation. The only comments were on the good side and it was the reasonable speed drag stability. It does not require a tremendous amount of attention to power management - attitude management to get speed back when you get off speed. The attitude stability is still bad. You can learn to live with it up to a point. In turbulence, the disturbances caused by me and the rough air while I was trying to manage everything else caused as much as three degree pitch attitude changes that had to be fought with. It is still not good enough so that I can do a real complete task of instrument monitoring. The attention required to pitch attitude control during the approach, especially in rough air, detracts from the rate at which I can keep a decent scan on the altitude and the IVSI. I have to concentrate too much on the glide-slope error, attitude, and speed to the detriment of a good cross check on the altimeter and IVSI. I will rate this a 4.

Second Evaluation. - If it is convergent, it is only very slightly convergent. It is not divergent. The basic problem is not so much speed control, although that is an annoying characteristic too, but pitch attitude stability. It requires a fairly complex pilot input to keep the pitch attitude where you want it. It is not very steady and any disturbances keep it going. It is not divergent so it isn't all that much work but it is a pain and I think it does affect your performance and it increases the amount of concentration required to fly it. I will rate this a 4 - 5 - D.

TIFS Configuration #4 (T_{2_α} = 3.6 sec)

Pilot A - The airplane is unstable in pitch and requires continuous control on the part of the pilot. It is sluggish and ponderous and hard to get everything stabilized down. Once you get a pitch rate going, you can take your pitch input out and it will keep going and even speed up. You have enough control authority to fly it. There is a tendency for a low frequency oscillation about the desired pitch attitude because of the difficulty in knowing when to put in the input to stop it. Behavior off-trim is abominable. There is a definite pitch up with a large control force needed to just keep it from departing. I had a tendency in every turn I made to pitch up and lose airspeed and it was difficult to correct quickly without inducing pitch attitude errors of as much as five degrees in the opposite direction. Airspeed control was very poor and the excursions were very undesirable. Airspeed was not very tightly tied to throttle. As a result of all this, the performance during the IFR task was poor.

The crosswind landing was the most difficult part of the evaluation because of the combination of pitch control requirements and the crosswind lineup correction. I attempted a de-crab technique, but was not able to do it successfully. The effect on sink rate and touchdown point was large. I will rate this a 9 - D.

Pilot B - It is unstable and has the same off-trim behavior as the other unstable ones. Maneuvering control was a little problem because of the airspeed control in a turn. Airplane motion is not suitable as you have to pull it up, stop it, and then hold it there. You had to concentrate on pitch but not drastically. Lateral-directional caused me more problems than anything else as I was over-controlling. Glideslope and localizer were no sweat except that the lateral-directional made me make bank angles and heading changes when I really did not want to. Turbulence effects increased the workload and made me sloppier and upset the lateral-directional causing heading problems. I will rate this a 6 - D.

Pilot C - (First Evaluation) - The primary problem is the lack of precision in pitch control. The airplane is not responsive to pitch control inputs. Large control inputs are required and you can't precisely position the airplane. If you don't think way ahead of the airplane, you get into a PIO very easily and it is especially noticeable in the flare. It feels like the airplane is getting bigger and bigger and there is more and more pitch inertia. The fact that it will diverge at any particular rate does not seem to bother me too much. Speed control requires a lot of attention. When you compound the PIO tendency with the distraction of speed control, it becomes a marginal task. Turbulence made a significant difference in the approach and in the performance. It actually aggravated the PIO tendency. I will rate this a 7 - D.

(Second Evaluation) - You could relax quite a bit flying this and still come out without too much difficulty compared to some of the others. During the rough air portion, there was a tendency to induce a long period PIO. I will rate this a 5 - D.

TIFS Configuration #5 (T_{2_α} = 2.0 sec)

Pilot A - Very unstable in pitch. Enough controllability to deal with it but the delay in response to a control application is considerable and, consequently, if you hold your input in until you see something developing, then you have already had it in too long.

Pitch task workload was extremely high. Pitch attitude was interfered with by the roll control and the de-crab maneuver. Control in turning flight was very difficult and, as a result, the ability to maintain, or reacquire glideslope and localizer was difficult. The pitch task quite adversely affected heading control. The best heading control is to mentally integrate bank angle errors because you do not have enough time to look at heading.

The crosswind landing was an unacceptably difficult task for me. I attempted to de-crab followed by a wing down. Airspeed control was suprisingly good compared to everything else I was having a problem with. Elevator forces were terrible but other control characteristics were the same as before. Control of pitch would be lost at some portion of a flight, probably in a combined task operation. In addition, turbulence does deteriorate it quite significantly by causing larger pitch excursions. I will rate this a 10- F.

Pilot B - This airplane is unstable and diverges at a fairly good rate. The nose hesitates and then it takes off because I never know how much is enough to get it to do what I want it to do. When the nose started moving off, I would push and push and it would do a reversal and I would go through a big PIO, and if I went to neutral force -- away it went. The timing of the control inputs is very unusual. I never did figure out how much to time them as the airspeed was off so much that I never knew where the trim was.

The longer I flew this configuration, the more I became convinced that this is a very bad back side operation on the power. I could not figure it out where I should have been on that power any time. The throttle movements were the most gross I have had to make yet. Elevator forces and gradients were also too high. The IFR operation was wild. The extremely bad back side operation combined with a relatively bad longitudinal instability made a bad workload. Turbulence was the least thing on my mind during the approach. I will rate this a 10 B.

Pilot C - Controllability is in question and it requires a lot of compensation to maintain control of it. Of course, you stay in a steady PIO all the way down. It really is not in control. I will rate this a 9 - D.

TIFS Configuration #6 (T_{2_α} = 5.0 sec)

Pilot A - It tends to depart in pitch attitude. Pitch response is slow and sluggish. It takes an extra bit of input to get it going, take it out and wait for it to reach the desired attitude and then stop it there. Timing is not unusual in the sense that you can stop it without too much pitch attitude error as long as you are looking at it when it needs stopping. The IFR portion was principally governed by the amount of attention you devoted to pitch attitude control. Lateral-directional characteristics were no problem but the airspeed control task was moderately difficult.

In the VFR segment, it was a real problem to perform the side step maneuver and keep the pitch under control and get the line-up under control and this affected the flare and touchdown. The cross-wind landing was a high workload maneuver. I was not able to eliminate all the crab angle prior to touchdown. The flare technique tended to be a bit of a panic operation in the crosswind landing. Normal flare was mostly accomplished by concentrating on pitch attitude and applying whatever elevator was necessary to keep the airplane from pitching nose down. Turbulence was not as much of a problem as the crosswind landing. I will rate this a 7 - C.

Pilot B - The airplane is symmetrically unstable nose up and nose down and it diverges at a good rate. I tend to overshoot on the pitch corrections because the stability level is low and I had trouble starting it and stopping it where I wanted. I was concentrating more on pitch attitude and accepting some sloppiness on the other gagues. Forces and force gradients interfered with my flying the airplane. Air-speed control was no more difficult than the other back side operations. I wasn't holding as tight a loop as normally because of the degraded time involved. We got 20 - 25 knots off on the high side. I do get concerned on the low side and I think the most I got off was 7 - 8 knots.

There is a degraded effect on the ability to acquire and maintain glide slope because the compounding of back side and pitch instability causes me to be very imprecise in making the corrections back on the glide slope. I had less trouble with the localizer. The tracking problem is just lack of attention because you are concentrating on pitch attitude. The workload decreases by about 50% when you go VFR.

Crosswind does not affect the task much. Landing is no big problem. It is just a matter of fighting the airplane to hold your attitude and let it touch. Turbulence seemed to amplify the difficulty in reading the instruments more than anything else. My body bouncing around occasionally put in an elevator input that I did not want. I will rate this a 7 - C.

Pilot C - The major thing wrong is the amount of pilot control to make an attitude change and the fact that double controls have to be used. The airplane has no sense of attitude stability at all. Once it is disturbed, it just keeps moving like it has infinite inertia. You are very busy on the controls.

This same thing is wild on making power changes at a fixed control position or fixed force. The small moments produced by the power changes produce pitch rates that must be stopped by the pilot or they will just continue. The pitch rate is continually being disturbed even in smooth air by the throttle changes required to produce flight path angle or speed changes so you are constantly in danger of losing it. The back side of the drag curve is obvious but I think that could be managed if you had better attitude stability on the airplane.

I found that on the ILS, especially in the turbulence where the rates were continually having to be stopped, I was really producing a long period PIO about a quarter of the frequency of the phugoid. I was just pumping it up and down trying to get the thing to stop where I wanted it and I don't think I ever got the oscillation damped out. To me, the combination says that control under those conditions is difficult even though control power is sufficient. I will rate this a 8 - D.

TIFS Configuration #7 (T_{2_α} = 3.2 sec)

Pilot B - I am having to concentrate on pitch control and trim is very important. The rate of divergence is somewhere above moderate. The forces are high on the elevator for this kind of divergence because it takes some pretty good inputs if I want to keep that pitch rate from building up on me or if I want to maintain a constant pitch attitude. If I want to catch it quickly, I have to put in a large elevator input, five degrees to ten degrees, and then quickly back off as it starts to do something and, therefore, the forces get pretty gross.

I am constantly inducing lateral-directional oscillations and I am not correcting them because of that high breakout force on that rudder. Having to push over the hump on the breakout usually gives me too much. Turbulence makes this problem worse because my body is bouncing. The same thing applies to reading the instruments. I will rate this a 7 - D.

Pilot C - This is the same sort of thing as the previous one (#18) -- only different. It looks like what you have got in there is a very rapid divergence but the stick free stability is improved. That stick free instability on the drag curve was really wild compared to this. Here I let it get 20 knots slow just to see what would happen and I have gotten control of the airplane at the glideslope intercept. I could not get away with that in the previous one. Here there is this constant PIO tendency. The previous one didn't have so much of a PIO as it was just running out of control. The worse it got, the worse it got both in drag speed and stick free stability. The further off you got, the more it tried to get away and the same with speed. This has got the same back side speed characteristics which isn't quite so bad if you don't have a big stick free stability problem. It is a little better than the stick free instability just to have a pure divergence. I will rate this a 7 - D.

TIFS Configuration #8 (T_{2_α} = 4.9 sec)

Pilot A - It is basically an unstable configuration. It requires an input to get it going and an input to make it stop. It tends to keep pitching and at an increased rate. Trim is not easy but it is very important. If you are off trim angle of attack, there is an unstable moment tending to increase the pitch attitude in the direction that it is already off.

Performance capability is good for acquisition of glideslope and localizer but workload is moderately high. There is a problem of roll control inputs inducing unwanted pitch inputs. This affected the glideslope and localizer tracking performance. In the crosswind problem, it was difficult to get the de-crab and crosswind correction and, at the same time, not have the pitch attitude depart. Airspeed control required attention but could be handled with the throttles. However, the airspeed was not connected as tightly to use of throttle as it should.

Elevator forces were light for small inputs but heavier for larger control disturbances. Aileron forces were heavy and rudder breakout force was objectionable. Flare technique was to produce tight attitude control and hold it, then make a small correction in attitude to correct the rate of sink and hold that while ground effect puts you on the runway. Turbulence stirs things up so that you are not conscious of errors developing and, consequently, you get a little farther off than you intended. I will rate this a 8 - D.

Pilot B - It is unstable longitudinally but it is a gradual acceleration away. Not a very rapid pitch runaway. You don't like the way the airplane moves ... because you have to move it and stop it or it will keep going. Trimming is no problem. Tracking and acquisition are no problems as long as you are near trim speed. Having an eight second engine response is important in all of this stuff on the back side. I have been able to hold airspeed fairly well in these maneuvers by just knowing I had to push the throttle forward when I did it and being able to pull the throttle off and accepting five knots fast if I got it. In turbulence, you spend more of your time on the instruments than you normally would. I will rate this a 5 - C.

Pilot C - I have been trying to figure out something else that I did not like about this airplane and I guess it is the high dihedral effect that it has and the way your damper works with it. It gives it, occasionally, a sense of roll angle stability and springs back against you. On a turn entry you have to hold force in and I do not like that. This seems to be a marginal PIO condition and I do not like it a bit. I didn't like a thing about it except it was controllable. All the platform stability was poor but it didn't diverge real fast. You couldn't get any real response out of it and the speed control was poor. Turbulence aggravated it. I will rate this a 5 - 6 - D.

TIFS Configuration #9 (T_{2_α} = 3.2 sec)

Pilot A - Pitch task is the primary problem. Response to pitch inputs is sluggish and it takes an opposite control to stop it but there appears to be adequate control. Trim is not well defined in terms of pitch rate. I noticed when I went off trim airspeed, I got practically no pitching moment. Behavior off trim airspeed is no problem.

Speed control was a significant problem. There is an airspeed tendency to depart the desired value and it makes you work on the elevator to control pitch and the throttle to control airspeed and it causes a degradation in your holding of heading and making corrections on the localizer. This combination of pitch difficulty and poor airspeed control made it difficult to get airspeed and altitude back to desired values when they got off. Lateral offset could be corrected fairly well. The crosswind landing was moderately difficult. Maneuvering did not affect touchdown point or sink rate but airspeed changes then sure did. I will rate it a 7 - D.

Pilot C - (First Evaluation) - Controllability becomes a problem due to the control power. The pitch attitude gets out of hand every now and then unless a lot of work is done on it. The slightest little input causes it to deviate from the very precise pitch control that is required to perform the task. Speed control is also very difficult for the same reason. I will rate this a 7.

(Second Evaluation) - OK, this is a 5 - 6 and the rough air rating is a D. But I like the notes to show, as I think about it more and more and this one in particular, there is no way you can show by performance on this that it would not be satisfactory but, basically, it should be called a 10. You can get in and say "How does it fly?" and it flys pretty good and you have to work pretty hard but you would not put anybody in an airplane with this characteristic to save your life. At high angles of attack this thing really goes and I just don't think it is safe in any way. The rating of 5 - 6 does not reflect that. It only reflects the amount of compensation and the kind of pilot effort that is required to get the thing to perform and to fly around and, as long as that is what we are doing, that is the kind of response you can get.

If you put this configuration in a whole mission simulation and exposed them to a failure from a very good airplane to this configuration, I think you would lose the airplane. On the other hand, if you started off in this airplane in an approach without giving them an abrupt failure, or unknown failure, I doubt very much if it would come out the same. That's really why we have this criteria on instability. What you are really after is something that can be disturbed and will tend to return to where it got bumped from. It may not recover real quick but at least it will attempt to recover by itself. These ILS tasks are very good to determine your ability to control the thing but I don't know if they get out the nitty-gritty. This case is controllable but the divergence is also a nasty thing and would get away from people.

TIFS Configuration #10 (T_{2_α} = 6.6 sec)

Pilot A - The pitch characteristics are objectionable. Pitch attitude requires a lot of concentration. You have to put an elevator input to initiate a change and another opposite one to stop it at the attitude you want. The airplane is constantly trying to pitch away from the desired attitude whenever I look away it seems, but the rate does not increase as if it were unstable. Trim is not too difficult to obtain. Aileron forces are lighter and more pleasant. The amount of roll due to rudder is significant but unless I did it on purpose I would not have noticed it. Lateral-directional characteristics seem pretty good.

The IFR portion went pretty well. The amount of attention needed on pitch attitude degrades heading, altitude and airspeed control somewhat because there is not enough time to devote to them. Turbulence disturbed pitch attitude a great deal more and required a lot more attention and control actions to keep the attitude where it belonged. Workload becomes quite high. I will rate this a 6 - E.

Pilot B - It is unstable dynamically. It appears to diverge at a greater rate nose-up than it does nose-down. Increased attention is required to pitch and a fair amount of attention to the throttle. It is controllable. I wouldn't want to have to do this routinely. I can get this airplane on the ground but it requires a lot of compensation. It requires more effort in turbulence. I accept a sloppier pilot job in turbulence. I will rate this a 6+ - D.

Pilot C - (First Evaluation) - The change in speed stability gives you a much better opportunity to handle the poor platform stability, or attitude stability, so that it improves it over the previous configuration (#3). I don't know if I went back and re-rated them that I wouldn't rate this a 4 and the previous one a 5, but this seemed a bit better than a 4 so we will just leave it the way it is. I will rate it a 3 - 4 - C.

(Second Evaluation) - I would rate this a 5 - 6 - D.

TIFS Configuration #11 (T_{2_α} = 4.0 sec)

Pilot A - Pitch control is decent. The pitch response is sluggish but surprisingly predictable. It took a pilot input to get it going; took awhile for the response to get going; and it took awhile for the pilot input to stop it. Elevator forces are heavy. It is not a real trimmable configuration but it didn't require much trim. Flares may have been the poorest characteristic. I should have exercised the airplane more in pitch.

Airspeed control was not a problem and required very little attention. Aileron forces and rudder breakout force were heavy. The crosswind landing was fairly difficult. Lineup and crosswind affected the flare and touchdown. Localizer task was interfered with by the lateral-directional characteristics and the inability to coordinate with the rudders due to the high breakout force. I will rate this a 6 - D.

Pilot B - It is moderately unstable and looks like it is in the bucket. It is continually oscillating in pitch. The pitch control task in the flare is not natural. You have to pull it to keep the nose from falling and then reverse to stop it. There is an inherent distaste for pushing that close to the ground. Airspeed is no problem. Also, airspeed was held close enough to where the trim wasn't a problem. In level flight, the decrease in the airspeed task compensated partially for the instability problem. Turbulence degraded the tracking task due to the bouncing of my body. I will rate this a 6 - C.

Pilot C - The big problem is a very rapid deterioration in pitch attitude stability here and it reflects itself in a control problem now. It is not quick to respond. It requires a large force for a large amount of time to get the rate reversed and there is a tendency to induce a PIO, especially in the VFR portion where you don't have a real fine pitch attitude scale to help you damp rates with. When you are looking out of the window at the visual scene in the VFR position, there is just a real definite tendency to PIO and it definitely affected the flare so that I felt the flare control induced a PIO that was easy to over-control and you could get an oscillation going during the flare. I will rate this a 6 - D.

TIFS Configuration #12 (T_{2_α} = 1.9 sec)

Pilot B - It is unstable and beyond the maneuvering point. It is very quick to diverge. There is enough elevator effectiveness to stop and recover from excursions of three degrees to five degrees. It gets into a long PIO and I don't know if it is pilot induced or not. There is some damping but the divergence is so quick it requires extensive monitoring of pitch attitude. It was not real difficult to maintain airspeed but I could not spend as much time and I accepted a greater error on the top side. I got concerned at about five knots slow and ten knots fast. It appears to be back side.

The forces are a little high in all three axes. I could have used a higher gradient. Rudder breakout still high. The whole task of flying the localizer and glideslope was increased during the crosswind. Turbulence is rough. Up and down pilot oscillation causes difficulty interpreting the instruments. I will rate this a 9 - D.

TIFS Configuration #13 (Stable)

Pilot A - It has a very predictable pitch response at constant power and looks like pitch attitude control will be very good. Elevator forces in a steady turn are very heavy and objectionable. There is some trim change with power that tends to create attitude errors. When I made power changes, the airplane responds as if it has a real strong head as far as going where it wants to in pitch attitude. You either have to manhandle it or return and retrimming causes you to lose your trim reference. I have a big thing that I am trying to move around and I don't have as much authority over it as I think I would like. Elevator control in the flare is very heavy and requires a lot of input. You have a tendency to get behind in the ground effect and it affects your control of touchdown point, sink rate and even the decrab maneuver during the crosswind landing. It also affected your ability to make localizer and glideslope corrections when you were close in. The airplane is inert in pitch.

Airspeed control was good. I didn't have to devote a lot of attention to keep it from getting out of control. Throttle changes did produce trim changes that had to be countered or airspeed would not do what you wanted. Desired performance requires considerable pilot compensation. I will rate it a 4.5 - C.

Pilot B - The airplane was obviously stable and had low elevator total effectiveness. The forces required to move the nose are higher than desired. Any off airspeed variation gave you high trim changes. Heavy elevator force was required to flare the airplane. You have to anticipate the ground effect. Sometimes I was inducing lateral movements that I didn't want because of the high longitudinal forces. Back side operation wasn't bad. Turbulence appeared to be sharper and more random than before. I will rate this a 4 - C.

Pilot C - ($Cm_{\delta e}$ = -.005) - It is obvious that we are looking at an airplane with no controllability. I will rate this a 9 or 10.

($Cm_{\delta e}$ = -.007) - Giving this configuration some control turned it into a useful configuration, an interesting airplane and I don't know if you need a lot more control than we had. I did some very violent maneuvering looking at the stability and at the adequacy of the control that we had and it was certainly adequate. The only unpleasant deficiency might be the back side kind of an operation and even that wasn't anything to get concerned about. Turbulence was no problem. I will rate this a 3 - A.

TIFS Configuration #14 (T_{2_α} = 4.8 sec)

Pilot A - High workload task in pitch. Requires a control input to get it going and an opposite control to stop it. Looks more unstable nose up than nose down. There is enough control to adequately handle the pitch task. Airspeed task was a low workload. Airspeed stayed more constant in turns than in straight and level flight. Lateral control was adequate with aileron forces a little on the heavy side and rudder breakout objectionable. Performance capability during IFR portion was fairly good. There was a degredation of all tasks in turbulence. The airspeed, pitch control and bank angle control tasks all became higher workload. This was the most objectionable characteristic. I will rate this a 5 - E.

Pilot B - This configuration is very highly unstable. It slowly diverges away and is on the back side of the drag curve. This stability level longitudinally is more compatible with the lateral-directional than the other one was with the strong stability (#13).

I still induce some lateral-directional oscillations but they are no worse than the other and maybe a little better because of the difference in the forces required and the lack of strong inputs due to the high longitudinal forces. Pitch control is somewhat annoying in that it wanders a little and is sloppy. Forces are fairly light. I will rate this a 4 - C.

Pilot C - I rate this a 5 - B. It is not uncontrollable. There is a problem but it it is reflected reasonably by the rating 5 - B.

TIFS Configuration #15 (T_{2_α} = 3.6 sec)

Pilot B - Fairly good instability and the nose just keeps going once you displace it. I think the forces are too high for this level of instability. Trim is real important. Even though it is hard to trim, it is because getting a zero rate at the time you get to trim is really difficult. If you don't trim it, you are going to have to hold a force and moderate some kind of a force to stop that pitch and it becomes very important that you are near trim depending upon the stick force gradient that you have and how much elevator power that you've got. The back side operation and turbulence just add to the workload. Rudder breakout force is too high for this airplane. I will rate this a 7 - D.

Pilot C - I would rate this a 6 - D. But here I am rating this same thing again. I am alright if I stay down the right hand column, adequate performance requires extensive pilot compensation, but if I look over in that other column, I find aircraft characteristics and then the next is deficiencies, one of them improvement, as opposed to required improvement, and I come up with different numbers every day.

TIFS Configuration #16 (T_{2_α} = 1.8 sec)

Pilot A - Very unstable in pitch and much more so at high angles of attack. Although it is unstable nose down, it is more so nose up, so there is some non-linearity. Response in pitch is sluggish so you don't see the consequence of your input until some time after you put it in and by then you should be putting an opposite control in. Difficult to get trim because you are never stabilized well enough to define it. Maneuvering control is like balancing a ball on top of an upside down bowl. Keep deviations small and you had a chance but if they get much larger you are near loss of control.

Airspeed control was very difficult. It takes large throttle corrections to bring it back. About all I can say about the IFR tasks is that I did it. You feel quite loaded because you know that pitch response is ready to bite you. I noticed I was willing to accept a long touchdown and even added a little power to lengthen the time I had available to make the offset correction so I didn't have to do anything very suddenly. Turbulence really wasn't that strong but it aggravated you on reading displays. It is hard to use the scale since I am already using my best efforts. I will rate this a 10 - C.

Pilot B - There is a strong degree of instability. It is pretty insidious. It seems to hesitate before it departs at a pretty good rate. It is important that it is trimmed. The standard off-trim behavior on these instabilities is you have to push or pull in the wrong direction to hold a force to stop it and then a good force to make it return pitch attitude-wise and then back off or it goes right on through. Maneuvering control in level flight catches you and turbulence amplifies it by appearing to be stable for a moment and then taking off. The poor handling qualities in pitch degrade everything because you spend too much time there.

Localizer tracking and glideslope acquisitions were difficult. Backside operation just adds to the problems. No difference in throttle feel. Crosswind landing is difficult but it is basically a problem of the ballooning effect. When you get VFR, the task simplified drastically. I will rate this a 10 - E.

TIFS Configuration #17 (T_{2_α} = 5.6 sec)

Pilot A - Attitude control is a problem because you have to start it and stop it when you are making pitch attitude changes. Configuration has a tendency to depart where you left it and can get out of hand quickly. Attitude control errors lead to glide slope errors due to the rate of sink errors. It is difficult to correct anything without having something get out of hand. The combination of pitch control workload and the tendency of the airspeed to depart a desired value caused a pretty high workload to stay on glide slope and that did not give you enough time to perform the localizer task. Roll inputs produced pitching moments which caused altitude errors. Turbulence effects were not great. I will rate this a 6 - C.

Pilot C - The apparent stick-free instability coupled with being on the back side of the drag curve makes it pretty interesting to fly. It doesn't seem to have much of a divergence in pitch if you are trimmed right around the trim speed but if you get off that, it is unstable and you really have to work at speed control and flight path control. You could probably live with this instability if there were a lot of damping. I will rate this a 5 - 6 - D.

TIFS Configuration #18 (T_{2_α} = 3.2 sec)

Pilot A - Demanding in pitch control but it seems stiffer about the desired angle of attack. Rather ponderous, which is good if you get stabilized at your desired pitch angle. Heavy forces make control of inadvertent pitch-ups very marginal. There is a definite pitch and roll coupling. There is an actual pitch rate induced during a roll. The slow and sluggish pitch response requires anticipation on the control inputs.

Airspeed tends to depart. It is very difficult to correct. You have to take off so much power that when you finally start to get near trim value, it has a good enough rate on that you must plan the throttle input back very closely. IFR workload was difficult because of pitch problem and lineup correction. Turbulence effects degraded the configuration and made me work harder. I will rate this a 7 - D.

Pilot C - Right off the bat we have such an unstable airplane that you can't get it down to a minimum speed which would be the 160 knots ÷ 1.3. About the time you get it down to that speed, you really don't have any control left as it is that unstable. How do you say that is acceptable? Surely, you have to have some kinds of criteria that keep you from giving that kind of thing to the pilot. If I had any indication that this airplane really had that kind of instability the first thing I would do is find out how unstable it was. If I got 10 knots below the approach speed and found that I was using a significant portion of the control power, you can bet that I would get this airplane on the ground as soon as possible and do something about that condition. It is so terribly unstable that you can't fly off speed and you are trimming backwards during the change in speeds, which isn't too terrible as you might not even know you are doing it. I will rate this an 8 - E.

TIFS Configuration #19 (T_{2_α} = 1.7 sec)

Pilot B - Grossly unstable. No tendency to return whatsoever. Anything that disturbs it causes such a high rate that it causes intense concentration on the pitch to maintain control of the machine in pitch, and not just the task. It is rather difficult to trim and the trim is slow compared to the instability so it takes a long time of holding that trim when you are 10 - 15 knots off to try to get it retrimmed. Forces get gross longitudinally because it requires a lot of elevator to stop some of the pitch rates that the airplane will generate by itself.

The standard back side stuff and the concentration on pitch control on top of everything else changes your cross-check.One more time- rudder still gives me trouble with that break-out force. I still overshoot on that and it causes lateral-directional problems. that cause heading problems. I will rate this a 9 - E.

Pilot C - The control authority is extremely limited. You are not able to control pitch attitude once the rate gets started. The pitch angular acceleration that you can induce even with maximum control deflections is very small. With that capability you are just forcing yourself into a PIO. I was looking around for control techniques that I might manage it with like large pulses but they are all inadequate. Very marginal situation to retain control. Control would be lost very quickly in too many instances if you were faced with this situation. Possibly if you were trained to fly this and flew it a lot you might live through it a few times. Let's call it a 9 - 10 because it is controllable up to a point.

TIFS Configuration #20 (Stable)

Pilot A - It was very stable. The elevator forces are very heavy and motions are quite large. To get a pitch rate, you had to put an input into the elevator and hold it. If you released it, the pitch rate stopped. Response was slow but predictable. Trim is easy and important. A small amount of out-of-trim is evidenced by heavy forces. I notice the lateral-directional problems more than any configuration thus far. I notice that when I want to make a correction in bank angle, it tends to stir up slide slip which affects my roll control and also degrades my heading control. Also, during turn entries, the nose drops and it requires large back elevator to keep the nose from falling. Ability to maintain or reacquire localizer is somewhat objectionable because of this.

Airspeed control was relatively good. As I initially flew the configuration for the first three approaches, there was a ground effect that came in and caused a nose down pitch at breakout altitude causing me to go below the glide slope. On the fourth approach in turbulence, I felt that it wasn't there. We decided that the pitching moment due to ground effect coming in at that altitude was an artifact of the TIFS, and simplification of the ground effect should be ignored in the rating. However, this configuration with very stable characteristics would be bad if the ground effect pitching moment came in that high because you could end up nose down, below glide path and in a dangerous flight condition. Crosswind landing is fairly difficult in that when you are making your lineup and corrections to the wing down and rudder control, it is easy to neglect supplying back elevator and end up hitting the ground too hard. The rating is based upon the ground effect as it was on the last approach. I will rate this a 5 - C.

Pilot B - Pitch control is positive but sluggish. No problems getting pitch attitude you want. It takes a fair amount of force to make the airplane do what you want. I made a fairly early flare and made sure I got that nose what I thought was coming up but the nose didn't really come up. It just did not go down. It is weird in ground effect because even after you are on the ground with throttles off, it does not want to decelerate much.

Airspeed is no problem. Almost no throttle management required. Lateral control is a bit of a problem but nothing worse than I expected. The variations in the lateral feel is basically a slide-slip variation. A key to flying this might be to keep that airspeed close to 160 knots because of the strong static stability probably causes the nose to want to pitch when you are off 10 knots. I will rate this a 6 - D.

Pilot B - ($C_{m_{\alpha_{GE}}}$ = -.0023) - This is very stable. Power and airspeed control are no problems. All I had to do was put the nose where I wanted it and it would stay there. Forces are too high. I am still getting a directional oscillation. Turbulence makes it more difficult to read the instruments because my body is bouncing around. I will rate this a 5 - D.

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CONTROLLER	MAXIMUM DISPLACEMENT	SURFACE GEARING	FORCE GRADIENT	BREAKOUT FORCE	HYSTERESIS
WHEEL (RAM'S HORN)	±46 deg	±0.435deg/deg	$\pm 2.56 \frac{N}{deg}$ $(0.58 \frac{lb}{deg})$	±11.1 N (2.5 lb)	ESSENTIALLY ZERO
COLUMN	+19 cm(7.4 in.) -17 cm(6.6 in.)	$+1.21 \frac{deg}{cm}$ $(3.2 \frac{deg}{in.})$ $-1.34 \frac{deg}{cm}$ $(3.4 \frac{deg}{in.})$	$+20.6 \frac{N}{cm}$ $(11.8 \frac{lb}{in.})$ $-22.5 \frac{N}{cm}$ $(12.8 \frac{lb}{in.})$	±17.8 N(4.0 lb)	ESSENTIALLY ZERO
RUDDER PEDALS	±10 cm(4.0 in.)	$\pm 2.94 \frac{deg}{cm}$ $(7.5 \frac{deg}{in.})$	$\pm 38.0 \frac{N}{cm}$ $(21.7 \frac{lb}{in.})$	±191 N (43 lb)	ESSENTIALLY ZERO

TABLE I. - CONTROL SYSTEM MECHANICAL CHARACTERISTICS

TABLE II. TEST CONFIGURATION MATRIX

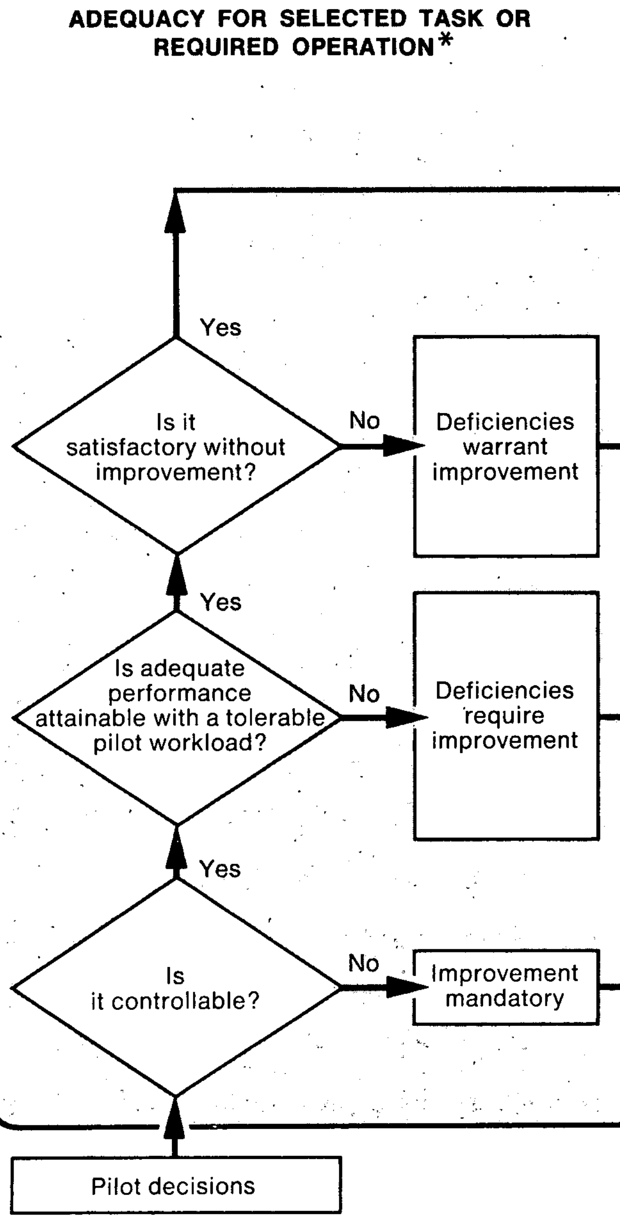
$C_{m_q}+C_{m_{\dot{\alpha}}}$	Nominal						5 × Nominal					
$\frac{\partial \gamma}{\partial V}$	Nominal (Backside)			Zero			Nominal (Backside)			Zero		
$C_m(\alpha)$ / C_{m_α}	linear	nominal non-linear	2 X nominal non-linear	linear	nominal non-linear	2 X nominal non-linear	linear	nominal non-linear	2 X nominal non-linear	linear	nominal non-linear	2 X nominal non-linear
Stable	(1)						(13)			(20)		
Slightly Unstable	(2)											
$T_2 \approx 8$ sec	(3)	(6)	(8)	(10)			(14)		(17)			
$T_2 \approx 4$ sec	(4)	(7)	(9)	(11)			(15)		(18)			
$T_2 \approx 2$ sec	(5)			(12)			(16)		(19)			

*Nominal indicates typical of reference airplane

TABLE III. PITCHING MOMENT COEFFICIENTS FOR EVALUATION CONFIGURATIONS

The following table indicates changes in pitching moment coefficients for the baseline and the various evaluation configurations (units are per deg. etc.)

Conf.	C_{m_o}	C_{m_1}	C_{m_2}	C_{m_3}	C_{m_q}	$C_{m_{\dot{\alpha}}}$	$C_{m_{\delta_e}}$	$\Delta C_{m_{\alpha_{GE}}}$	$\Delta C_{m_{\delta_{e_{GE}}}}$
BL	+.00427	-.0026	+.0001	$+.35\times10^{-6}$	-.00267	-.00137	-.00342	-.0023	-.00038
1	+.091620	-.00771	0	0	↓	↓	-.00502	-.0057	-.00060
2	-.005633	-.00043	0	0	↓	↓	-.00342	-.00264	-.00038
3	-.010190	-.00010	0	0	↓	↓	↓	-.00250	↓
4	-.020824	-.00067	0	0	↓	↓	↓	-.00217	↓
5	-.052310	+.00295	0	0	↓	↓	↓	-.00121	↓
6	+.008854	-.00286	+.0001	0	↓	↓	↓	-.00250	↓
7	-.001780	-.00209	+.0001	0	↓	↓	↓	-.00217	↓
8	+.027898	-.00562	+.0002	0	↓	↓	↓	-.00250	↓
9	+.017264	-.00485	+.0002	0	↓	↓	↓	-.00217	↓
10	-.010190	-.00010	0	0	↓	↓	↓	-.00250	↓
11	-.020824	+.00067	0	0	↓	↓	↓	-.00217	↓
12	-.052310	+.00295	0	0	↓	↓	↓	-.00121	↓
13	+.091620	-.00771	0	0	-.01285	-.00685	-.00502	-.0057	-.00060
14	-.019443	+.00057	0	0	↓	↓	-.00342	-.00222	-.00038
15	-.043330	+.00230	0	0	↓	↓	↓	-.00149	↓
16	-.098160	+.00627	0	0	↓	↓	↓	+.000184	↓
17	+.018645	-.00495	+.0002	0	↓	↓	↓	-.00222	↓
18	-.005246	-.00322	+.0002	0	↓	↓	↓	-.00149	↓
19	-.060072	+.00075	+.0002	0	↓	↓	↓	+.000184	↓
20	+.09162	-.00771	0	0	↓	↓	-.00502	-.0057	-.00060
1-mod	↓	↓	↓	↓	-.00267	-.00137	-.00700	↓	↓
13-mod	↓	↓	↓	↓	-.01285	-.00685	-.00700	↓	↓



AIRCRAFT CHARACTERISTICS	DEMANDS ON THE PILOT IN SELECTED TASK OR REQUIRED OPERATION*	PILOT RATING
Excellent Highly desirable	Pilot compensation not a factor for desired performance	1
Good Negligible deficiencies	Pilot compensation not a factor for desired performance	2
Fair — Some mildly unpleasant deficiencies	Minimal pilot compensation required for desired performance	3
Minor but annoying deficiencies	Desired performance requires moderate pilot compensation	4
Moderately objectionable deficiencies	Adequate performance requires considerable pilot compensation	5
Very objectionable but tolerable deficiencies	Adequate performance requires extensive pilot compensation	6
Major deficiencies	Adequate performance not attainable with maximum tolerable pilot compensation. Controllability not in question	7
Major deficiencies	Considerable pilot compensation is required for control	8
Major deficiencies	Intense pilot compensation is required to retain control	9
Major deficiencies	Control will be lost during some portion of required operation	10

* Definition of required operation involves designation of flight phase and/or subphases with accompanying conditions.

TABLE IV. HANDLING QUALITIES RATING SCALE

INCREASE OF PILOT EFFORT WITH TURBULENCE	DETERIORATION OF TASK PERFORMANCE WITH TURBULENCE	RATING
NO SIGNIFICANT INCREASE	NO SIGNIFICANT DETERIORATION	A
MORE EFFORT REQUIRED	NO SIGNIFICANT DETERIORATION	B
	MINOR	C
	MODERATE	D
BEST EFFORTS REQUIRED	MODERATE	E
	MAJOR (BUT EVALUATION TASKS CAN STILL BE ACCOMPLISHED)	F
	LARGE (SOME TASKS CANNOT BE PERFORMED)	G
UNABLE TO PERFORM TASKS		H

TABLE V. TURBULENCE EFFECT RATING SCALE

TABLE VI. COMPARISON OF TIFS BASELINE AND REFERENCE AIRPLANE TRIM DATA

(W = 231 483 lb; V_c = 160 knots; h_{CG} = 2000 ft and 16 ft)

	Thrust (lbs)		α (deg)		δ_e (deg)	
	free air	in g.e.	free air	in g.e.	free air	in g.e.
Reference airplane (CG @ 53% C_r)	57451	49345	13.62	11.41	-1.06	-6.21
TIFS Baseline	58332	49717	13.83	11.54	-1.93	-7.26

TABLE VII. SUMMARY OF MEASURED SIMULATION LATERAL-DIRECTIONAL CHARACTERISTICS FOR ALL CONFIGURATIONS AND REFERENCE 11 MINIMUM REQUIREMENTS

PARAMETER	SIMULATION VALUE REF. AIRPLANE & EVAL. CONFIGS.	REFERENCE 11 MINIMUM REQUIREMENTS	
		LEVEL 1	LEVEL 2
T_{2_s}	(STABLE)	12.0 MAX.	12.0 MAX.
τ_r	0.17 sec	3.0 MAX.	3.0 MAX.
ω_{nd}	0.91 rad/sec	0.4 MIN.	0.4 MIN.
ζ_d	0.21	0.08 MIN.	0.02 MIN.
$\zeta_d \omega_{nd}$	0.19 rad/sec	0.15 MIN.	0.05 MIN.
$\lvert \phi/\beta \rvert$	3.0	—	—

TABLE VIII. COMPARISONS OF T_2 VALUES MEASURED FROM ANGLE OF ATTACK, PITCH ATTITUDE AND CALIBRATED AIRSPEED

TIFS CONFIG. NO.	PREDICTED TIFS T_2 sec	MEASURED T_{2_α} sec	MEASURED T_{2_θ} sec	MEASURED T_{2_V} sec
[REF. A/C]	–	4.0	4.8	3.6
BASELINE	–	3.7	4.6	3.5
1	STABLE	STABLE	STABLE	STABLE
2	60	8.4	13.4	4.9
3	8.0	5.5	8.4	4.3
4	4.0	3.6	4.2	3.4
5	2.0	2.0	2.0	1.4
6	8.0	5.0	6.9	4.4
7	4.0	3.2	3.7	3.3
8	8.0	4.9	9.4	4.1
9	4.0	3.2	3.6	3.2
10	8.0	6.6	9.7	4.5
11	4.0	4.0	4.2	3.4
12	2.0	1.9	1.9	1.8
13	STABLE	STABLE	STABLE	STABLE
14	8.0	4.8	7.2	5.0
15	4.0	3.6	4.4	3.5
16	2.0	1.8	1.8	1.5
17	8.0	5.6	9.3	5.0
18	4.0	3.2	3.7	3.6
19	2.0	1.7	1.8	1.5
20	STABLE	STABLE	STABLE	STABLE

TABLE IX - MEASURED DIVERGENCE TIME, FLIGHT-PATH STABILITY, AND TRIM VALUES FOR THE EVALUATION CONFIGURATIONS

Config.	$T_{2\alpha}$ (Sec)	$d\gamma/dV$ (deg/kt)	Level-flight thrust (lb) free air	Level-flight thrust (lb) in g.e.*	Trim α (deg.) free air	Trim α (deg.) in g.e.	Trim δ_e (deg.) free air	Trim δ_e (deg.) in g.e.
Baseline	3.7	.11	58332	49717	13.83	11.54	-1.93	- 7.26
1	Stable	.13	58416	51576	13.84	12.03	-2.01	-10.22
2	8.4	.11	58374	50183	13.83	11.66	-1.92	- 8.01
3	5.5	.11	58380	50013	13.83	11.62	-1.91	- 7.75
4	3.6	.11	58356	49635	13.83	11.53	-1.91	- 7.19
5	2.0	.10	58362	48740	13.82	11.31	-1.90	- 5.86
6	5.0	.11	58374	49918	13.83	11.60	-1.91	- 7.61
7	3.2	.11	58362	49553	13.83	11.50	-1.91	- 7.05
8	4.9	.11	58374	49824	13.83	11.57	-1.91	- 7.46
9	3.2	.11	58362	49434	13.83	11.48	-1.91	- 6.89
10	6.6	≈0	58374	52042	13.83	11.60	-1.91	- 7.70
11	4.0	≈0	58368	51985	13.83	11.50	-1.91	- 7.13
12	1.9	≈0	58368	51840	13.82	11.28	-1.90	- 5.81
13	Stable	.13	58421	51538	13.84	12.03	-2.01	-10.23
14	4.8	.11	58362	49692	13.83	11.54	-1.91	- 7.29
15	3.6	.10	58368	48992	13.82	11.37	-1.90	- 6.22
16	1.8	.08	58362	47789	13.82	11.07	-1.89	- 4.45
17	5.6	.11	58362	49490	13.83	11.49	-1.91	- 6.99
18	3.2	.10	58368	48778	13.83	11.32	-1.90	- 5.91
19	1.7	.08	58344	47581	13.82	11.02	-1.89	- 4.14
20	Stable	≈0	58362	52533	13.85	12.01	-2.01	-10.15
1-mod	Stable	.11	58046	49169	13.72	11.41	-1.31	- 6.50

* in g.e. corresponds to c.g. height of 16 ft

CONF. NO.	$T_{2\alpha}$ SEC.	$d\delta/dV$ DEG/KT	PILOT	PILOT COMMENTS	PILOT RATING	TURB RATING
1	STABLE	.13	A	Airplane is stiff in pitch. Response is predictable but sluggish. Elevator forces are fairly heavy and control motions are objectionably large especially in turning flight and in ground effect during flare and touchdown. Airspeed wanders and requires some attention.	5	C
			B	Airplane has strong static stability. Five knots off airspeed creates pitch problems because airplane is hunting a new trim position. Elevator gradient a little high to get desired response. Needs more g capability. Lateral-directional characteristics are relatively sloppy. Airspeed control no problem.	5	C
			C	Airplane has a very strong sense of stability and high longitudinal stick forces. It is springy in pitch. Offspeed case produces large out-of-trim force... Airplane generally tended to maintain speed. Plenty of maneuvering capability. Hardest correction was from below glide slope up to it.	3	A or B
			C	It is a stable airplane and has very low pitch damping. Low control power combined with short period oscillation causes a PIO tendency. Transfer of speed errors into pitching moments cause very high stick forces to maintain glideslope.	5	E
2	8.4	.11	A	Pitch attitude requires a lot of attention but is predictable. Airplane continues to respond in pitch until you put in a control input to stop it. Lateral-directional control inputs cause undesirable longitudinal aircraft motions. Somewhat difficult to maintain airspeed.	6	C
			B	Light to moderate instability. Pitch control is still sensitive but much less of a problem than some of the others. It diverges up and down in pitch at a moderate rate. Much tighter loop on the crosscheck.	5	D
			C	Airplane is slow and sluggish in pitch response and it maintains pitch rates that are induced by pilot inputs or disturbances. It is difficult to fly pitch attitude precisely. Speed control was poor; I could only hold it within ± 10 knots. Within this range there is a 3° or 4° attitude change required to maintain same flight path.	6	D
3	5.5	.11	A	Pitch attitude control is a high workload task. Airplane behavior is unstable off trim airspeed. Good elevator authority but I would like better precision. Use of ailerons induces a pitching velocity. You must add power properly and in phase with bank angle or airspeed will rapidly diverge. There is plenty of thrust for airspeed control.	7	D
			B	Airplane drifts away rather than zooming off. Precision of the control is not what I would desire; sloppy but controllable. Pitch continues to diverge unless you stop it. Airspeed changes induce pitch changes. When you went VFR, there was an order of magnitude decrease in task. Turbulence affected instrument scan.	6	D
			C	It had reasonable speed-drag stability and didn't require excessive attention to power and attitude management to get speed back. Pilots inputs and rough air disturbances caused as much as 3° pitch attitude changes. Attention required to pitch attitude control, especially in turbulence, detracts from my instrument scan rate.	4	
			C	The basic problem is pitch attitude stability. It requires a fairly complex pilot input to keep pitch attitude where you want it. It is not divergent but any disturbance keeps it going.	4-5	D
4	3.6	.11	A	Unstable in pitch and requires continuous pilot control. Sluggish, ponderous and hard to stabilize. Pitch rates will continue after pilot input is removed. Tendency for a low frequency oscillation about desired pitch attitude. Behavior off-trim is abominable. Tendency to pitch up and lose airspeed in every turn. Airspeed control was very poor and excursions were very undesirable. Crosswind landing was most difficult part to do.	9	D
			B	Unstable. Maneuvering control was a problem due to airspeed control in a turn. Had to concentrate on pitch but not drastically. Lateral-directional caused the most problems. Turbulence increased the workload.	6	D
			C	Primary problem is lack of precision in pitch control. If you don't think way ahead of the airplane, you get into a PIO, especially noticeable in the flare. Feels like airplane is getting bigger and there is more pitch inertia. Speed control requires a lot of attention. Turbulence aggravates PIO tendency.	7	D
			C	You could relax flying this and come out without too much difficulty. Tendency to induce long period PIO in turbulence.	5	D
5	2.0	.10	A	Very unstable in pitch. Enough controllability to deal with it but elevator forces are terrible. Pitch task workload was extremely high and interfered with by roll control and decrab maneuver. Pitch task adversely affected heading control Best heading control is to mentally integrate bank angle errors as there isn't time to look at heading. Control of pitch would be lost at some time.	10	F
			B	Airplane is unstable and diverges at a fairly good rate. Nose hesitates and then takes off. Timing of control inputs is very unusual. I couldn't figure out where I should have been on the power anytime. Throttle movements were the grossest yet. Elevator forces and gradients were too high. IFR operation was wild. Turbulence was least thing on my mind.	10	B
			C	Controllability is in question. It requires a lot of compensation to maintain control.	9	E

TABLE X. SUMMARY OF SIGNIFICANT PILOTS' COMMENTS

CONF. NO.	$T_{2\alpha}$ SEC.	$d\delta/dV$ DEG/KT.	PILOT	PILOT COMMENTS	PILOT RATING	TURB RATING
6	5.0	.11	A	Departs in pitch attitude and pitch response is sluggish. Timing is not unusual as long as you are looking at it when it needs stopping. Difficult to perform sidestep maneuver and keep pitch and lineup under control. Affected flare and touchdown. Crosswind landing was a high workload maneuver and flare tended to be a panic operation.	7	C
			B	Symmetrically unstable and diverges at a good rate. I had trouble precisely controlling pitch attitude. I was concentrating more on pitch attitude and accepted sloppiness on other gauges, esp. airspeed. Combination of back side and pitch instability degraded my ability to acquire and maintain glideslope. Landing is no big problem. Turbulence affected my ability to read the instruments.	7	C
			C	The airplane has no sense of attitude stability. Once disturbed, it keeps moving. Pilot is very busy on the controls. The small moments produced by power changes produce pitch rates that must be stopped. On the ILS, esp. in turbulence, I was continually producing a long period PIO and I couldn't damp it out. Control is difficult but control power is adequate.	8	D
7	3.2	.11	B	I'm concentrating on pitch control. Trim is important. Divergence rate is above moderate. Elevator forces are high if I want to keep the pitch rate from building up. I'm constantly inducing lateral-directional oscillations and I'm not correcting for them because of the high rudder breakout force.	7	D
			C	There is a very rapid divergence but stick free stability is improved. There is a constant PIO tendency. It is a little better to have a pure divergence than stick free instability.	7	D
8	4.9	.11	A	Basically an unstable configuration. Tends to keep pitching and at an increased rate. If you're off trim angle of attack there is an unstable moment tending to further increase pitch attitude. Roll control inputs induce pitch inputs which affect IFR performance. Airspeed control required attention but could be handled with throttles. Turbulence stirs things up enough that you're not aware of other errors developing.	8	D
			B	Unstable longitudinally but a gradual acceleration away. You have to move it and stop it or it keeps going. Tracking and acquisition are no problem if you're near trim.	5	C
			C	I don't like the high dihedral effect that this airplane has and the way the damping works with it. It gives it a sense of roll angle stability. On a turn entry you have to hold force in. This is a marginal PIO condition. Platform stability was poor but it didn't diverge real fast. Speed control was poor.	5-6	D
9	3.2	.11	A	Pitch response is sluggish and it takes an apposite control to stop it. Tendency for airspeed to depart desired value. Combination of pitch difficulty and poor airspeed control makes you work on elevator and throttle and degrades heading and localizer tasks. Crosswind landing was moderately difficult.	7	D
			C	Controllability becomes a problem due to control power. Slightest input causes pitch to deviate from the very precise control required to perform the task. Speed control has same problem.	7	
			C	There is no way you can show by performance on this that it would not be satisfactory but basically it should be called a 10. I can say that it flys pretty good and you have to work pretty hard but you wouldn't put anybody in an airplane with this characteristic to save your life. At high angles of attack, this thing really goes. It would get away from people.	5-6	D
10	6.6	≈0	A	The airplane is constantly trying to pitch away from desired attitude but the rate does not increase. Takes an elevator input to initiate a change and another to stop it. Attention required to pitch degrades heading, altitude and airspeed control. Lateral-directional characteristics are good. Turbulence disturbs pitch attitude and increases workload.	6	E
			B	It's unstable dynamically. Diverges faster nose-up than nose-down. Increased attention is required to pitch. I wouldn't want to do this routinely. Requires more effort in turbulence.	6+	D
			C	The change in speed stability gives you a much better opportunity to handle the poor platform stability.	3-4	C
			C	No comments.	5-6	D
11	4.0	≈0	A	Pitch response is sluggish but surprisingly predictable. All control forces are heavy. Lateral-directional characteristics and high rudder breakout interfered with localizer task. Crosswind landing was fairly difficult. Flares may have been poorest characteristic. Airspeed control was no problem.	6	D
			B	It is continually oscillating in pitch. Pitch control task in the flare is not natural. You have to pull to keep nose from falling and then reverse to stop it. Airspeed is no problem and compensated partially for instability problem.	6	C
			C	Very rapid deterioration in pitch attitude stability. It requires a large force for a large amount of time to reverse the rate. Tendency to induce a PIO esp. during the VFR portion. Could get an oscillation going during the flare.	6	D
12	1.9	≈0	B	Unstable and beyond maneuvering point. Diverges quickly. It gets into a long PIO. It wasn't real difficult to maintain airspeed. IFR task increased during crosswind. Turbulence affected ability to interpret instruments.	9	D

TABLE X. (Continued)

CONF. NO.	$T_{2\alpha}$ SEC.	$d\gamma/dV$ DEG/KT.	PILOT	PILOT COMMENTS	PILOT RATING	TURB. RATING
13	STABLE	.13	A	It has a very predictable pitch response. Some trim change with power that creates attitude errors. Airplane responds as if it has a real strong head and goes where it wants in pitch. Elevator control in the flare is very heavy. You get behind in ground effect and it affects the entire landing. Airspeed control is good.	4.5	C
			B	Obviously stable and had low elevator total effectiveness. Forces required to move nose are higher than desired. Heavy elevator force to flare. You must anticipate ground effect. I induced some unwanted lateral movements.	4	C
			C	For air work only, it is obvious we are looking at an airplane with no controllability.	9 or 10	
14	4.8	.11	A	High workload task in pitch but there is adequate control. More unstable nose-up than nose-down. Airspeed stayed more constant in turns than straight and level flight. Turbulence degraded all tasks.	5	E
			B	Highly unstable. It slowly diverges. Stability level longitudinally is more compatible with lateral-directional than other one (#13). Induced some lateral-directional oscillations. Pitch control is annoying. Forces are fairly light.	4	C
			C	It is not an uncontrollable situation. There is a problem but it is reflected in the rating.	5	B
15	3.6	.10	B	Fairly good instability. Nose just keeps going once displaced. Forces are too high. Trim is real important, but difficult to do. If you don't trim you must hold a force and moderate about it to stop pitch. Rudder breakout too high.	7	D
			C	No comments.	6	D
16	1.8	.08	A	Very unstable in pitch especially at high angles of attack. More unstable nose-up. Pitch response is sluggish. Opposite controls needed. Trim is difficult. You must keep deviations small or you lose control. I accepted a long touchdown and added power to keep from making sudden movements during landing. Airspeed control was very difficult.	10	C
			B	Strong degree of instability. It hesitates before departing at a good rate. Trim is important. Poor handling qualities in pitch degrade everything else. Localizer and glideslope tasks were difficult. Backside adds to problem. Turbulence amplifies problems. When you get VFR, the task is simplified drastically.	10	E
17	5.6	.11	A	Must start it and stop it to make pitch attitude changes. Combination of pitch control workload and airspeed tendency to depart cause high workload to stay on glideslope and perform localizer task. Roll inputs produce pitching moments.	6	C
			C	It doesn't diverge much in pitch until you get off of trim speed and then it is unstable and you really have to work at speed and flight path control. You could live with this if there were a lot of damping.	5-6	D
18	3.2	.10	A	Demanding in pitch control. Slow and sluggish pitch response requires anticipation on control inputs. Pitch rates induced during a roll. Airspeed tends to depart. Very difficult to correct. Large power reduction required creates large pitch rates as you near trim. IFR workload was difficult. Turbulence was degrading.	7	D
			C	It is so unstable that you can't get to a minimum speed without running out of control. Can't fly it off speed and you are trimming backwards during change in speeds.	8	E
19	1.7	.08	B	Grossly unstable. Intense concentration on pitch is needed to maintain control after any disturbance. Forces get gross longitudinally. Trim is difficult and slow. High rudder breakout still causing lateral-directional problems.	9	E
			C	You are unable to control pitch attitude once a rate gets started due to limited control authority. You force yourself into a PIO. Control would be lost very quickly in too many instances.	9-10	
20	STABLE	0	A	It was very stable. Elevator forces are heavy. Pitch rate stopped when elevator was released. Slow but predictable pitch response. When making bank angle corrections, I tended to stir up sideslip which affected roll and heading control. Nose drops during turn entries. Airspeed control was good. Crosswind landing was difficult. Easy to neglect back elevator when making corrections and hit too hard.	5	C
			B	Pitch control is positive but sluggish and takes a fair amount of force. Wierd in ground effect. Doesn't want to decelerate. Airspeed is no problem. Lateral control is a bit of a problem; basically a sideslip variation.	6	D
1 MOD.	STABLE	.11	A	Pitch attitude control is best I've seen. Airspeed control is beautiful . I had difficulty with lateral-directional characteristics in ground effect. Fairly high workload as far as forces required, but acceptable.	4	
13 MOD.	STABLE	.11	C	Giving this configuration some control turned it into a useful configuration. I did some violent maneuvering and the control is certainly adequate. Turbulence was no problem.	3	A

TABLE X. (Concluded)

12 RUN NUMBER

WEIGHT = .2315E 06 LBS CG = .5300E 02 PERCENT

TURBULENCE PROFILE

SIGMA = .3104E 01 HX = -.2747E 00 FEET
VWN = -.1526E-01 FPS VWE = -.3052E-02 FPS

AT X=3000 FEET (BEFORE THRESHOLD)

WHEEL ALTITUDE = .1990E 03 FT LATERAL DEVIATION = .1230E 03 FT
VC = .1655E 03 KNOTS. ALTITUDE RATE = -.1731E 02 FT/SEC
AUTOTH REF SPEED = .1650E 03 KNOTS

AT X=0 FEET (THRESHOLD)

WHEEL ALTITUDE = .3886E 02 FT LATERAL DEVIATION = -.2530E 01 FT
VCAL .1670E 03 KNOTS. ALTITUDE RATE = -.1183E 02 FT/SEC
PITCH ATTITUDE = .1077E 02

AT MAIN GEAR TOUCHDOWN

X = .3650E 04 FT LATERAL DEVIATION = -.8221E 00 FT
VCAL .1455E 03 KNOTS ALTITUDE RATE = -.4199E 01 FT/SEC
GAMV = -.9845E 00 DEGREES DELTS = .0000E 00 DEGREES
PITCH ANGLE = .1287E 02 ROLL ANGLE = -.3483E-01 DEGREES
MAIN GEAR TRACKING ANGLE = -.1386E 00 DEGREES

12 RUN NUMBER

-.9065E 00 = MINIMUM TAIL HEIGHT
.0000E 00 = TIME, INITIAL TOUCH DOWN TO NOSE WHEEL TOUCH DOWN
.0000E 00 = TIME, INITIAL TOUCH DOWN TO 50 PERCENT BRAKE APPLICATION
.0000E 00 = TIME, INIT TOUCH DOWN TO REVERSER 2 ACTUATION
.1289E 02 = TIME FROM 30 FEET TO TOUCH DOWN (SEC)
.0000E 00 = HEIGHT AT AUTOTHROTTLE DISENGAGE (FT)
.3406E 04 = MW TOUCHDOWN FROM 30 FT ALT (FT)
.0000E 00 = NW TOUCHDOWN FROM 30 FT ALT (FT)
.0000E 00 = 50 PERCENT BRAKES FROM 30 FT ALT (FT)
.0000E 00 = REVERSER ACTUATION FROM 30 FT ALT (FT)

ALTITUDE-FT	RATE-FT/SEC
.9961E 02	-.1457E 02
.6959E 02	-.1080E 02
.4964E 02	-.1214E 02
.3991E 02	-.1203E 02
.2993E 02	-.9942E 01
.2454E 02	-.1060E 02
.1993E 02	-.9921E 01
.1490E 02	-.2788E 01
.9803E 01	-.5520E 01
.5780E 01	-.5197E 01
.3979E 01	-.3324E 01
.1986E 01	-.1067E 01

TABLE XI. DIGITAL PRINTOUT OF APPROACH AND LANDING PARAMETERS
(TIFS Configuration 15)

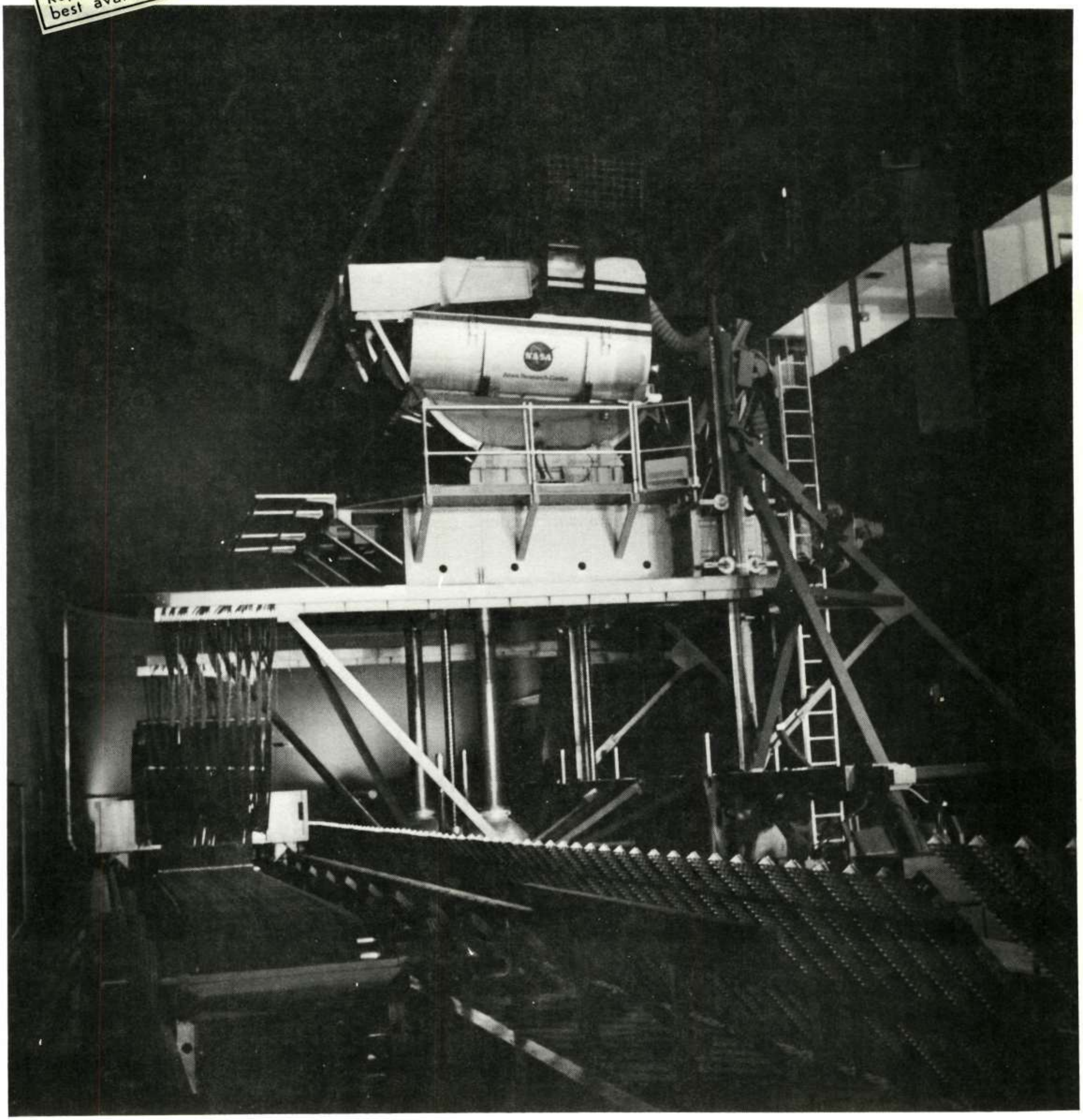


Figure 1.- Flight Simulator for Advanced Aircraft.

A71-2132

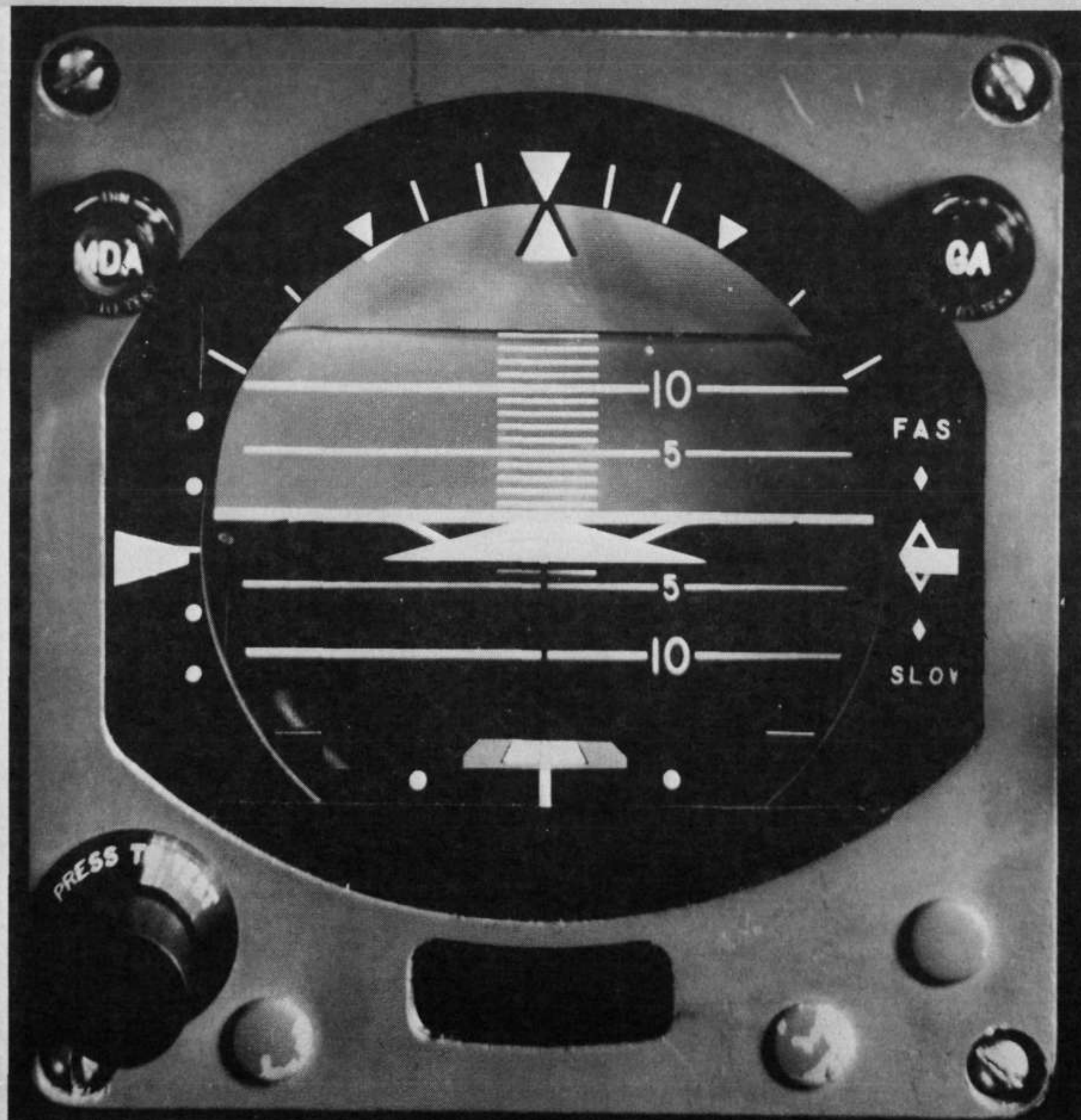
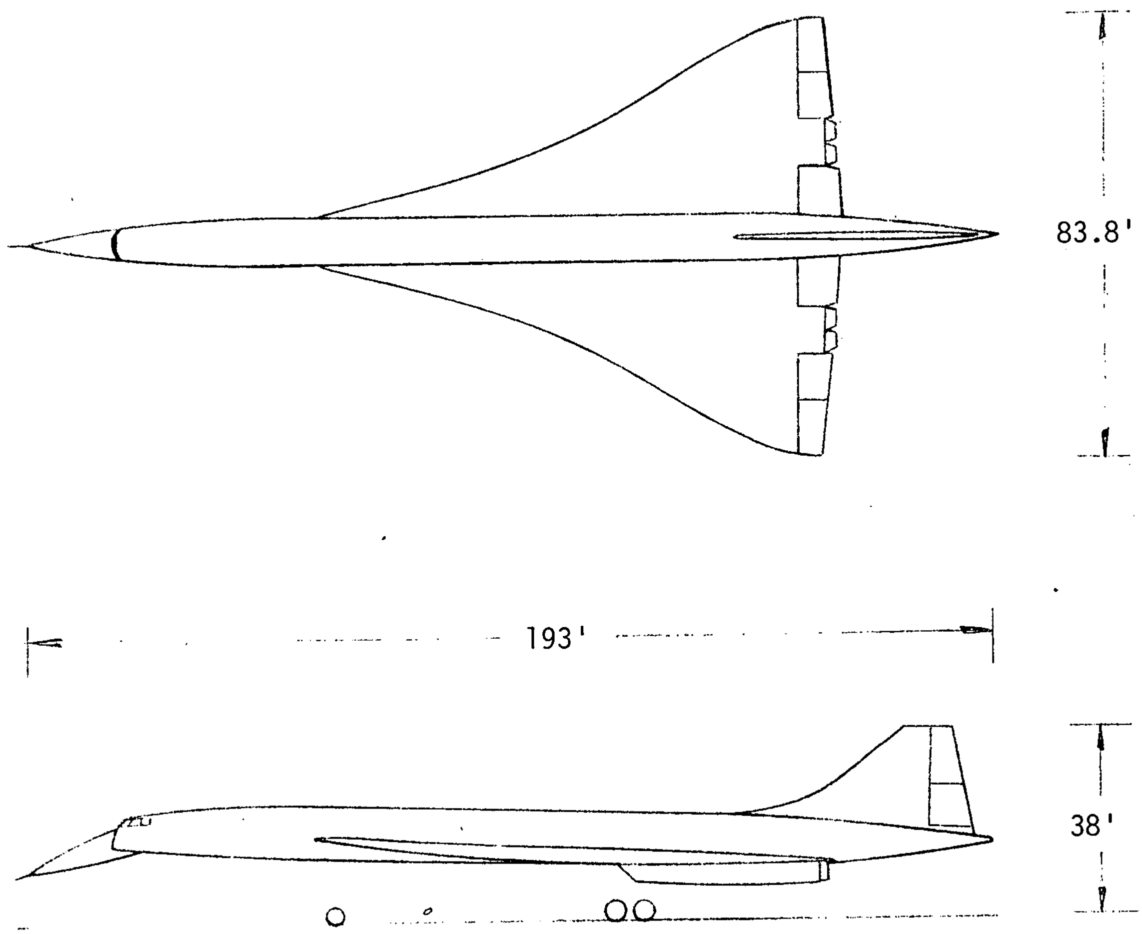


Figure 2.- Attitude Director Indicator (full scale)



Weight	231,483 lbs.
Wing area	3856 sq. ft.
Reference chord	90.7 ft.
Moments of inertia	
I_{xx}	1,700,490 slug ft^2
I_{yy}	15,118,400 slug ft^2
I_{zz}	16,526,100 slug ft^2
I_{xz}	- 355,830 slug ft^2

Figure 3.- Two view drawing and major physical characteristics of reference airplane.

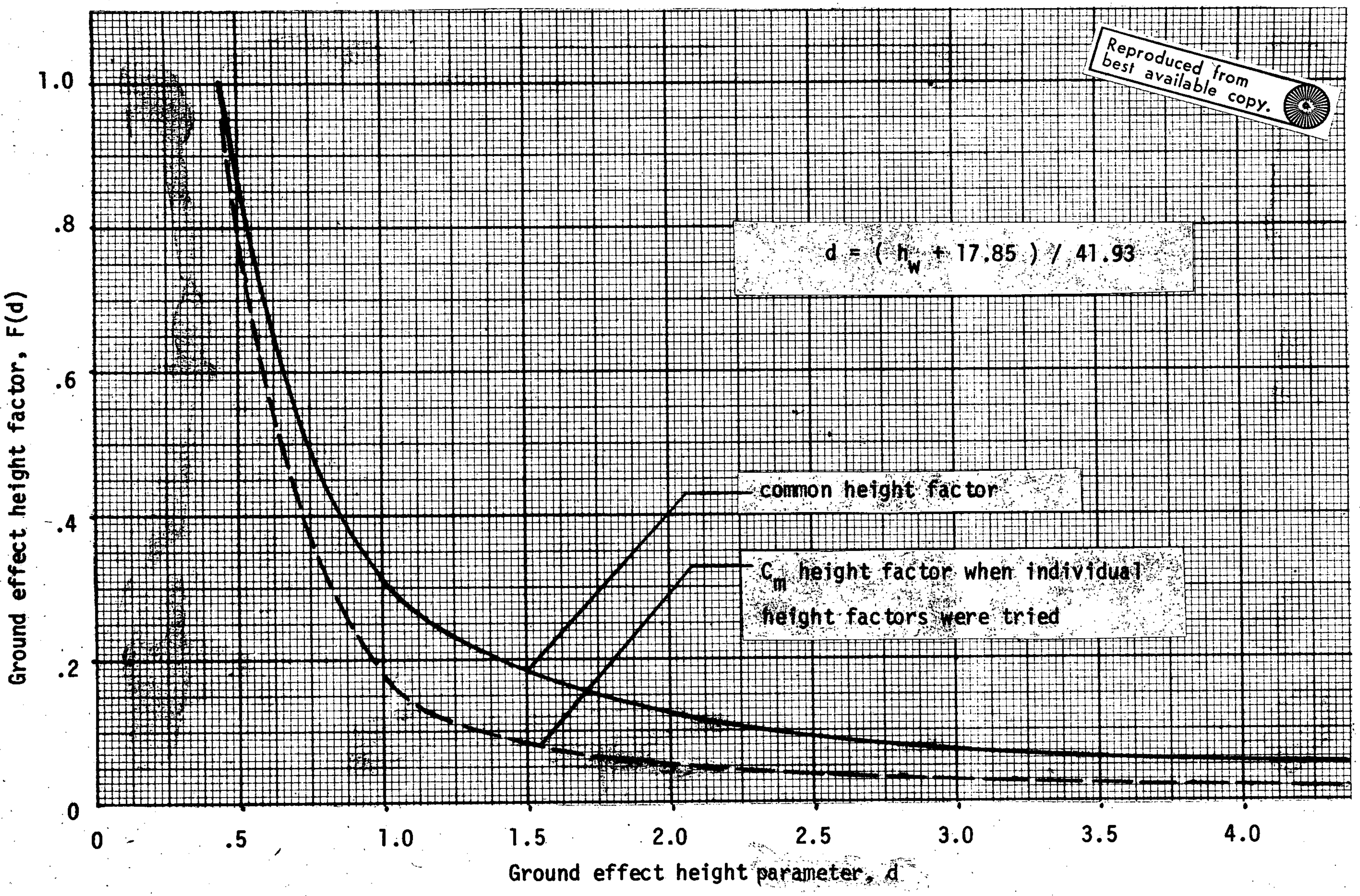


Figure 4.- Ground effect height factor used for simulation of TIFS baseline and test configurations.

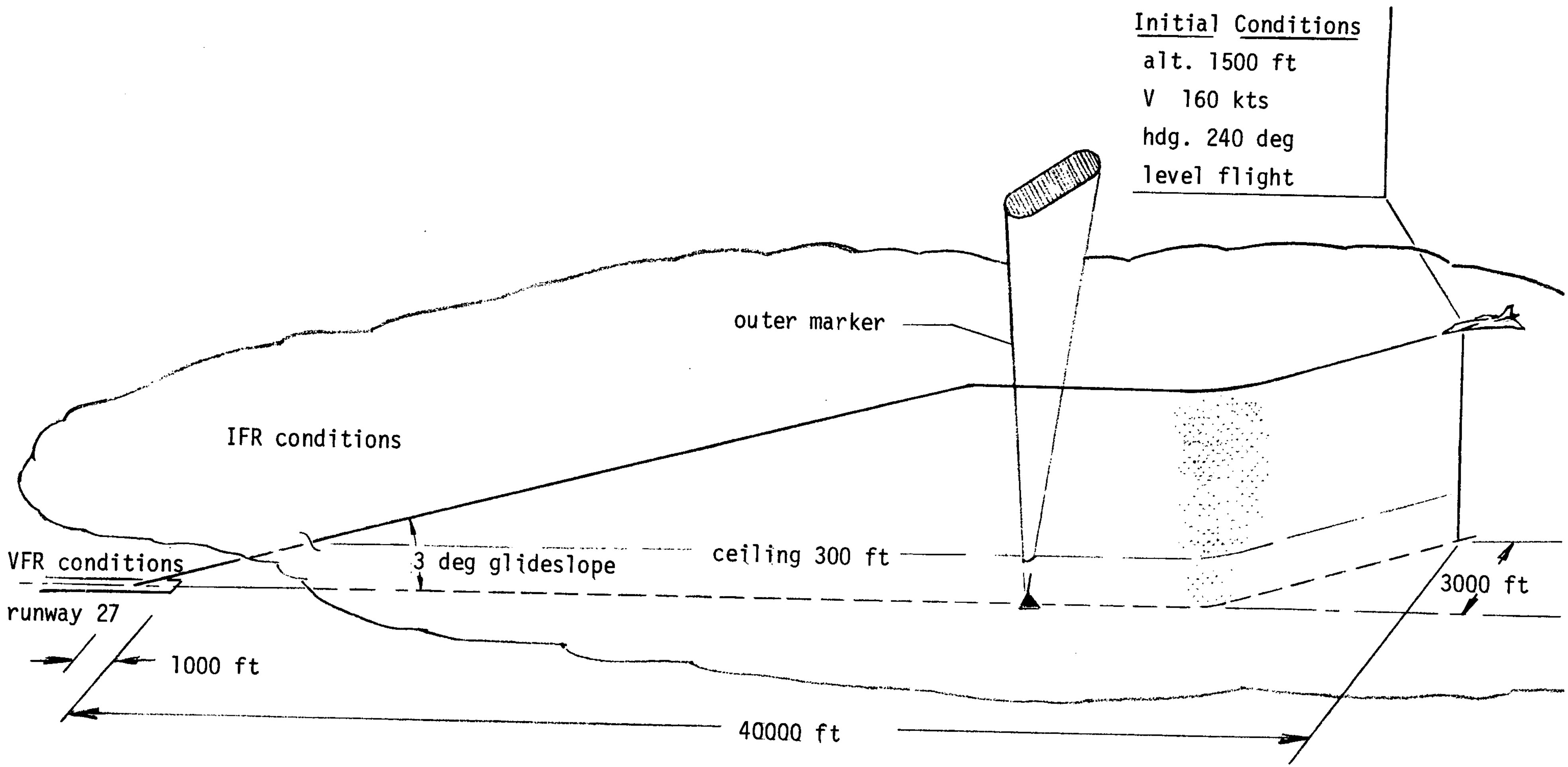
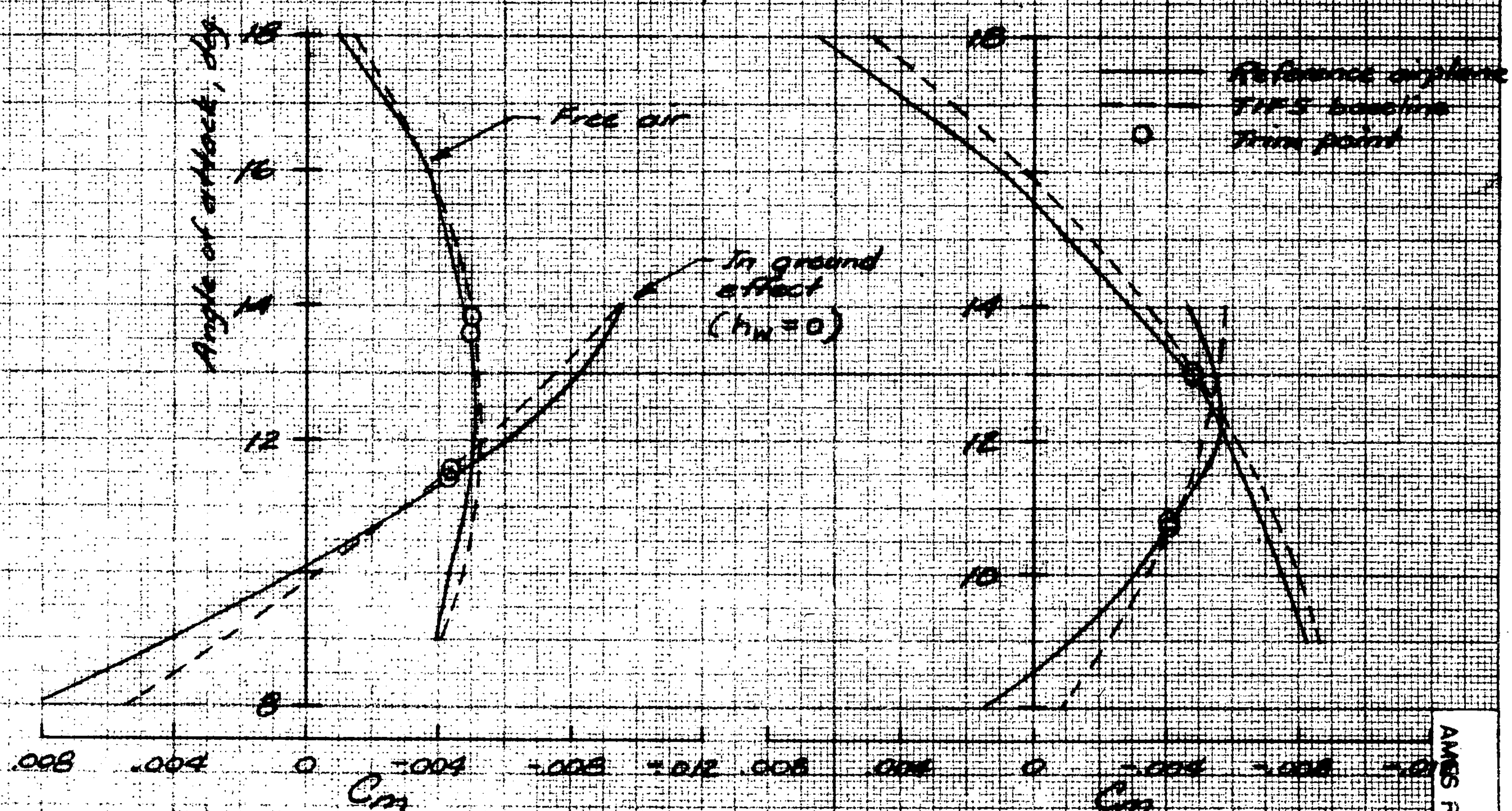


Figure 5.- Landing approach flight profile used in the piloted evaluations.



(a.) Baseline

(b.) CG shifted .02 C_r aft of baseline

Figure 6.- C_m vs. α plots for verification of TIFS baseline model

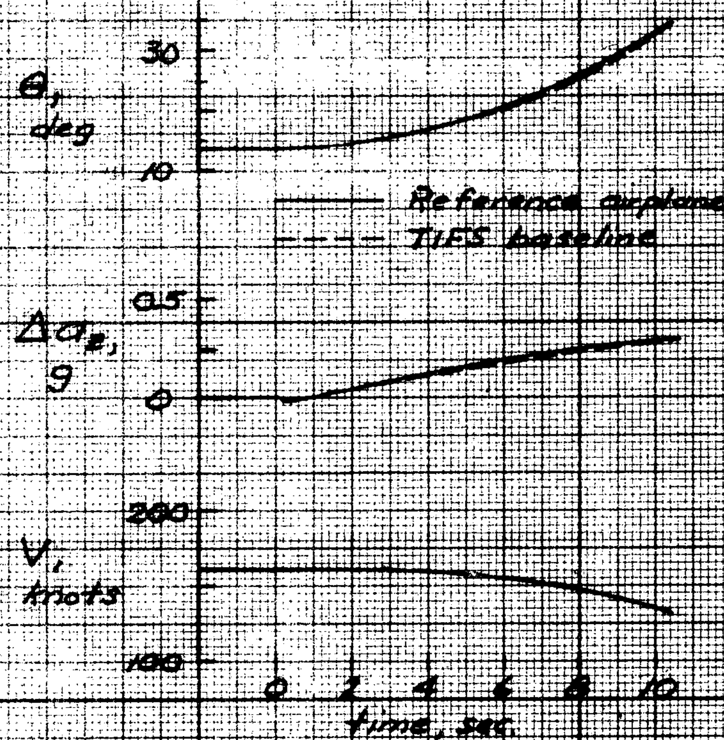


Figure 7.- Pitch dynamic response verification of TIFS baseline model. One-deg elevator step at t=0.

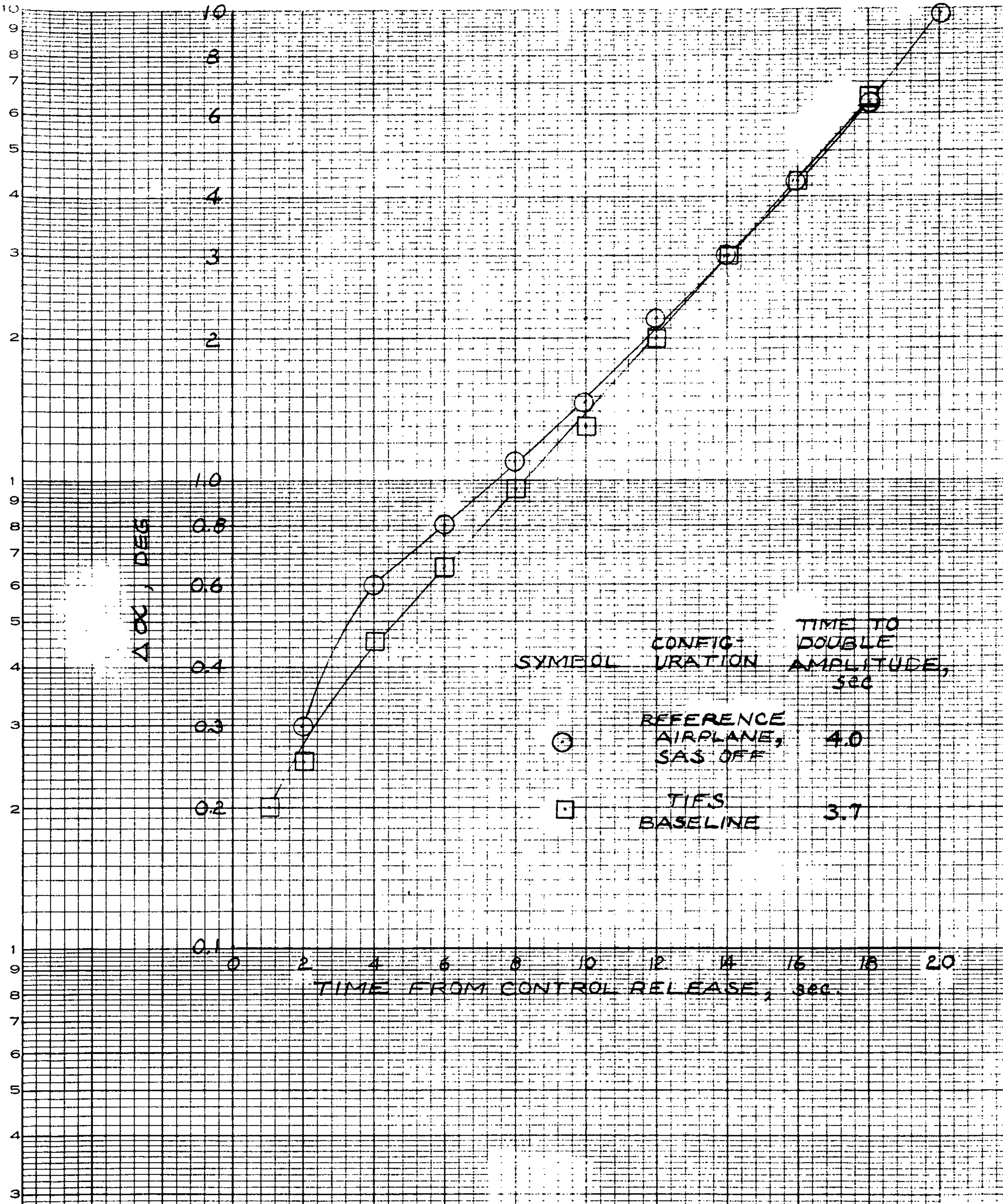


Figure 8.- Work-sheet for determination of measured time to double amplitude for reference airplane and TIFS baseline.

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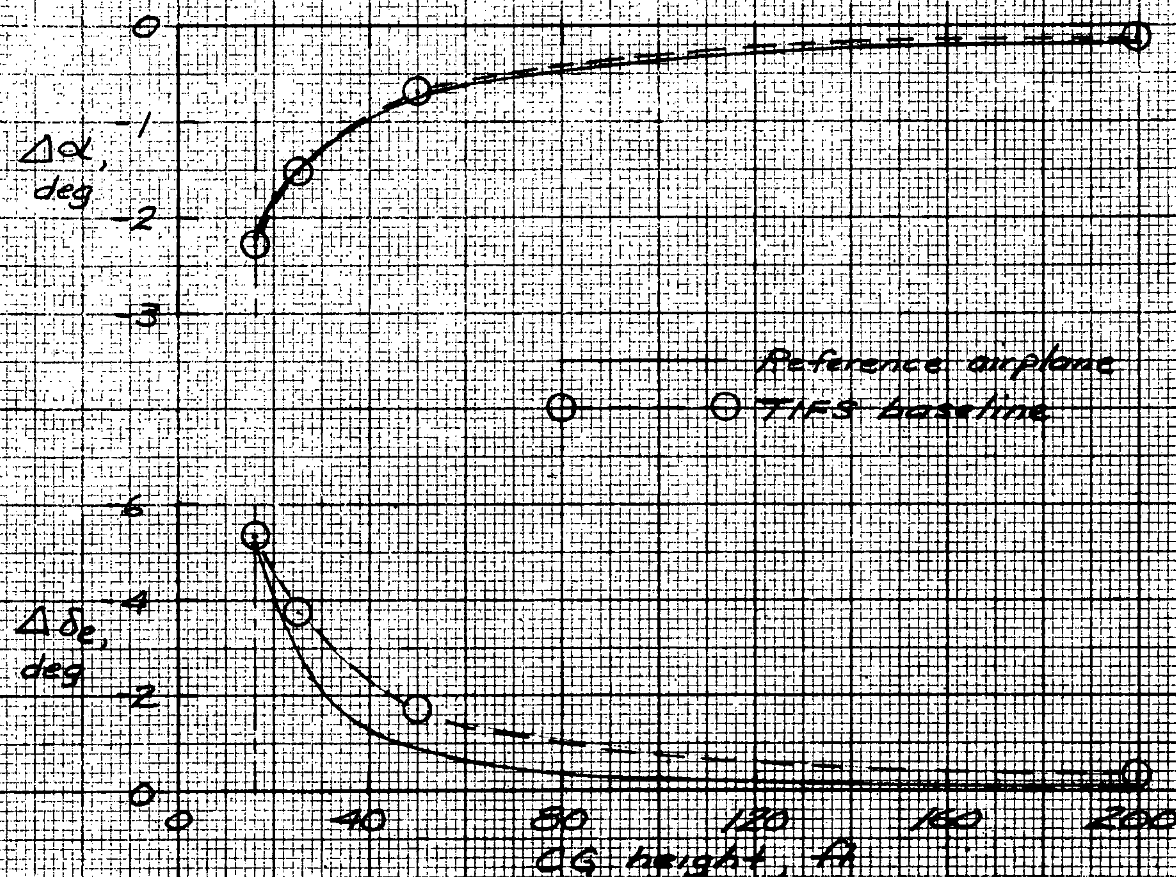
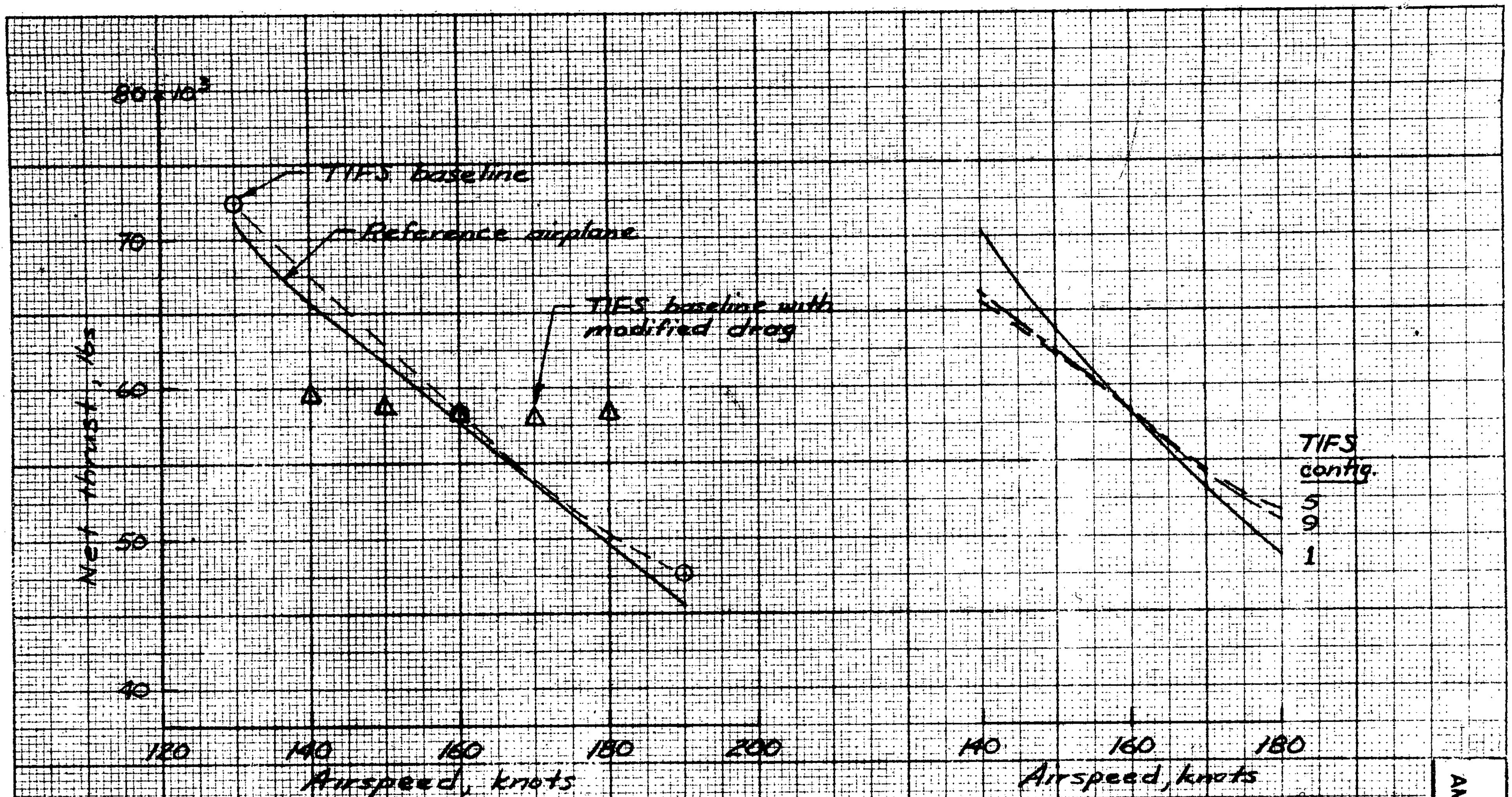


Figure 9.- Documentation of ground effect showing incremental angle of attack and incremental elevator to trim at various heights.



(a.) Baseline and reference configurations (b.) Evaluation configurations

Figure 10.- Thrust required for level flight versus airspeed
Gear down, altitude 2000 ft.

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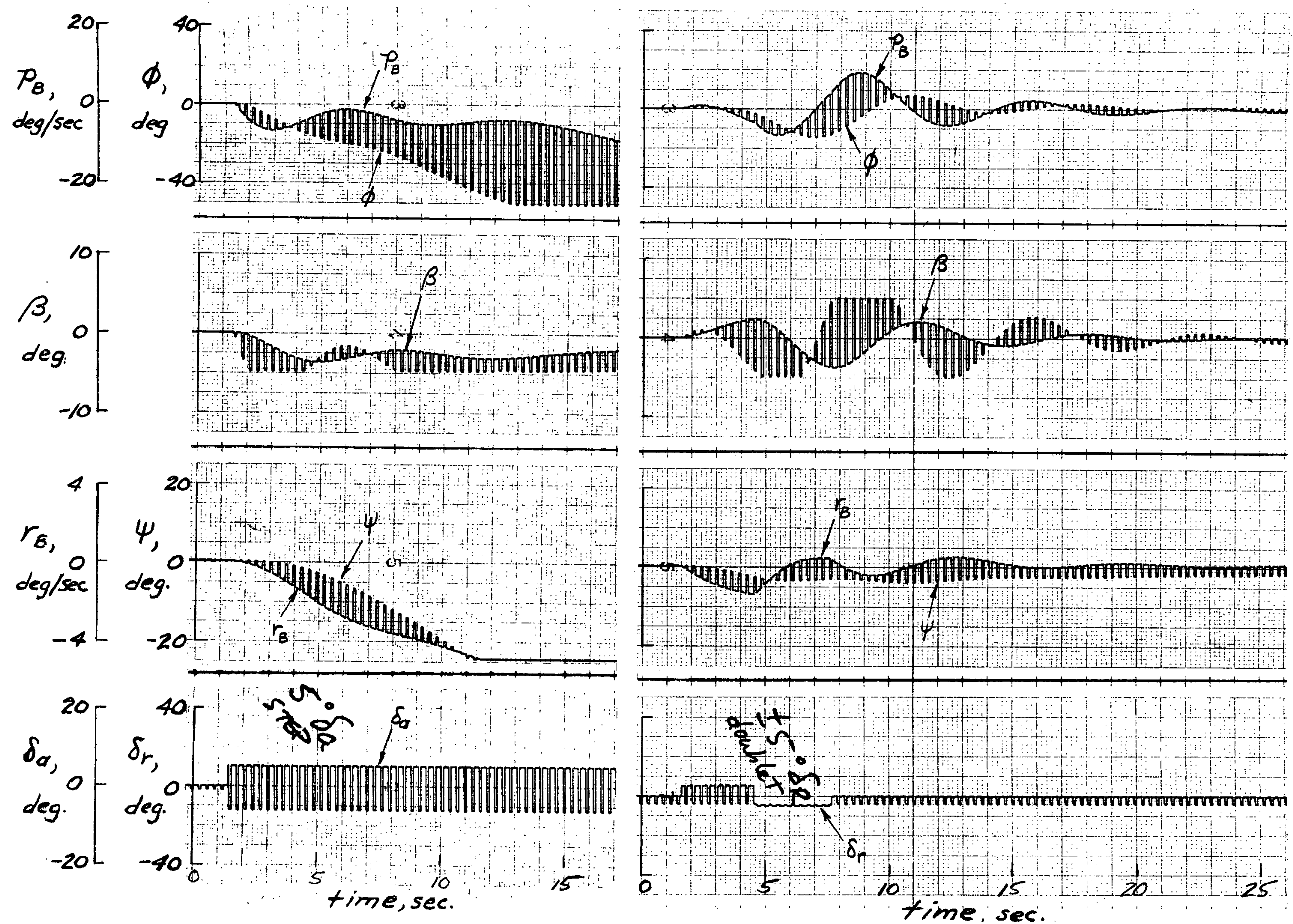


(a.) Aileron step (b.) Rudder doublet

Figure 11.- Lateral-directional dynamic responses of unaugmented reference airplane

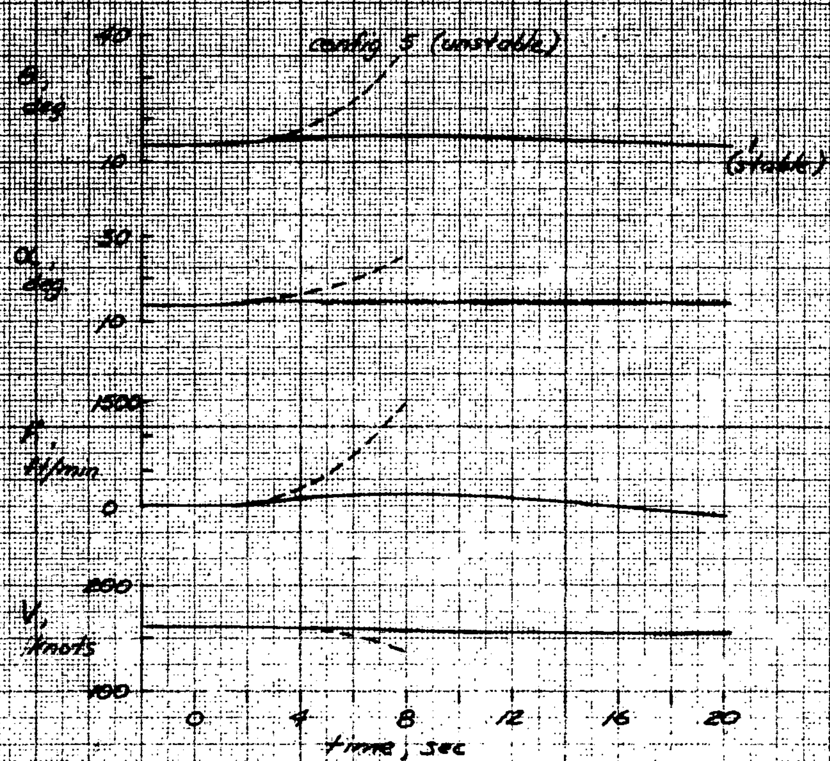
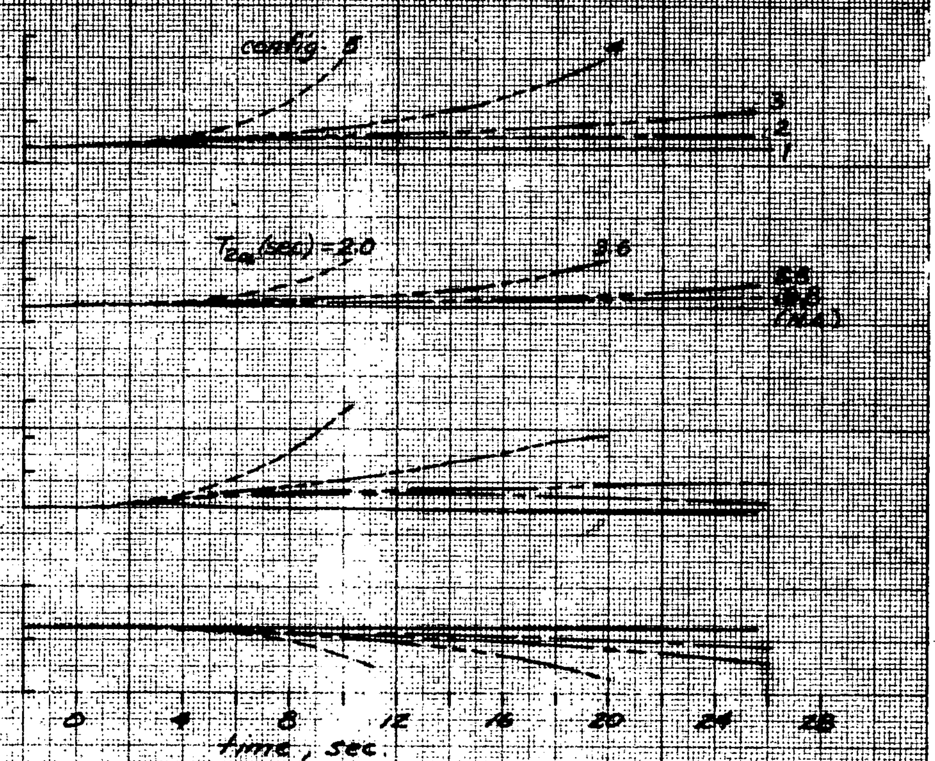
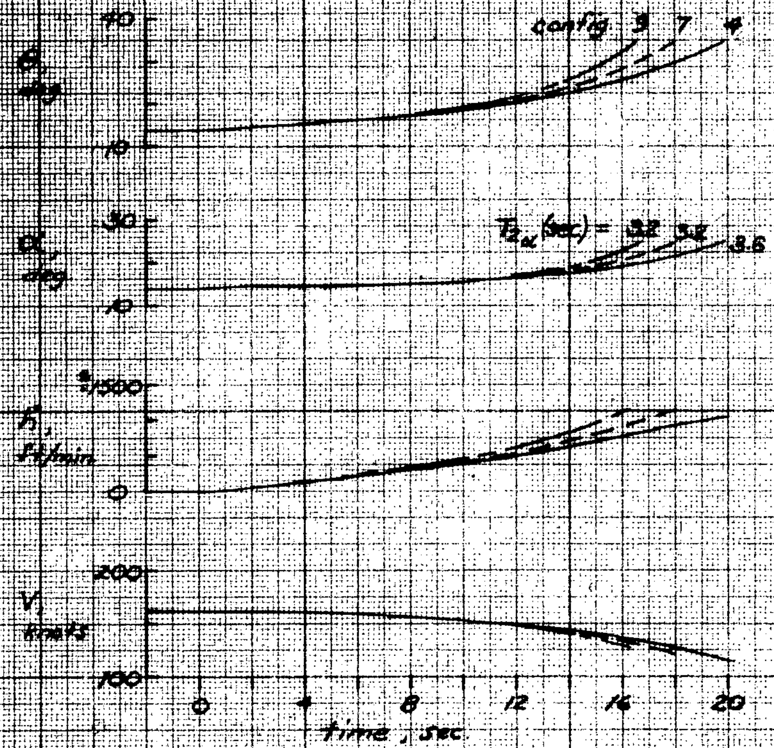


Figure 12.- Comparison of stable and unstable airplane responses to elevator step (-1 deg at t=0)

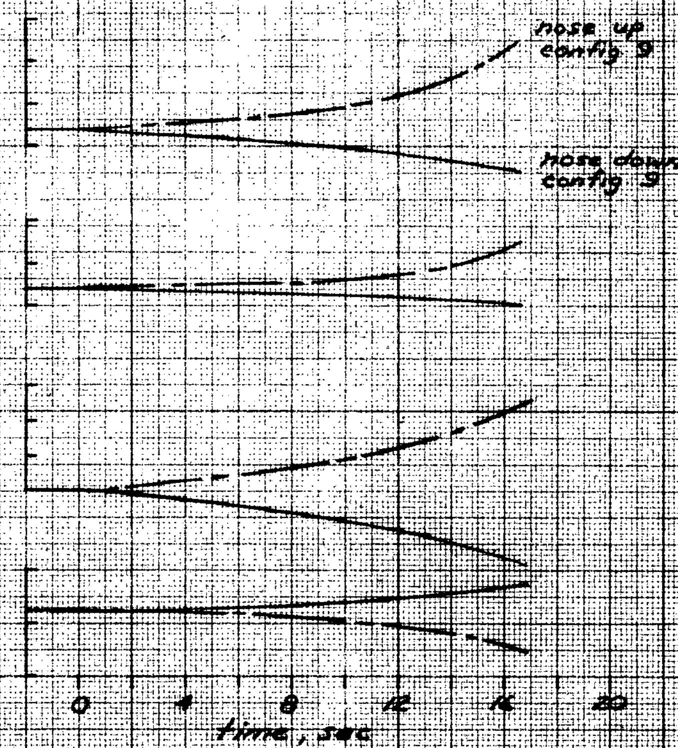


(a.) Comparison of linear $C_m(\alpha)$ configurations 1 - 5

Figure 13.- Comparison of effects of various stability characteristics on airplane response to elevator pulse (-5 deg for 0.2 sec at t=0)

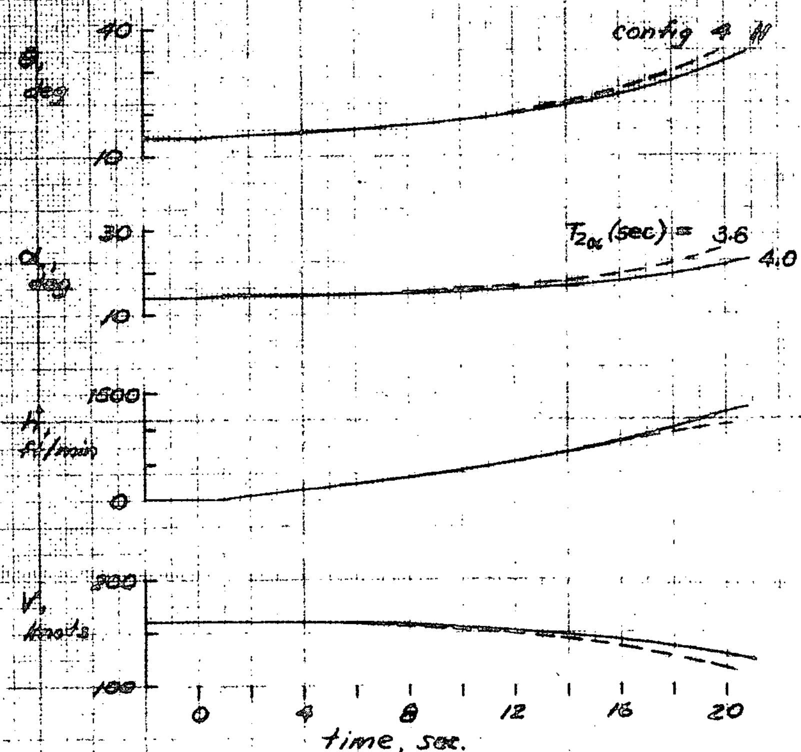


(b.) Effect of varying the degree of non-linearity in $C_m(\alpha)$.

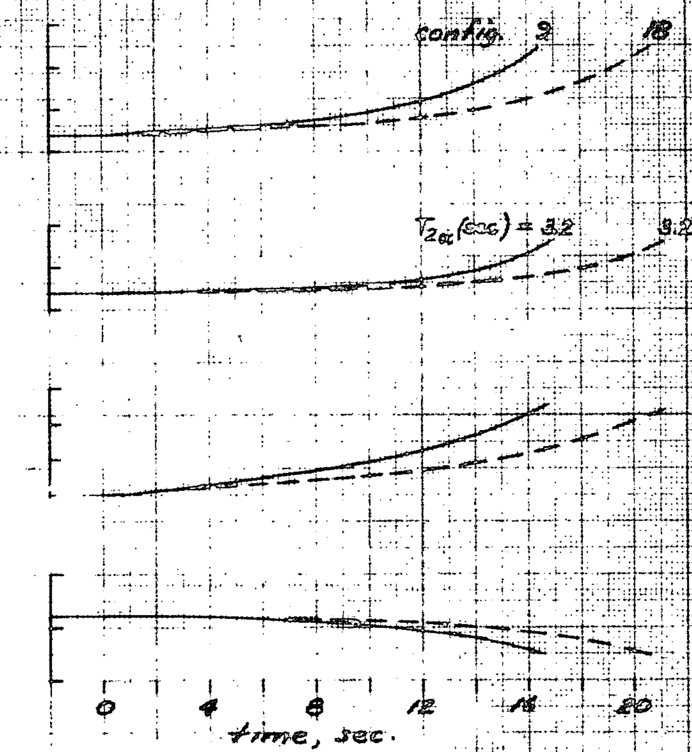


(c.) Comparison of nose-up response with nose-down response for non-linear $C_m(\alpha)$ configuration 9

Figure 13.- Continued

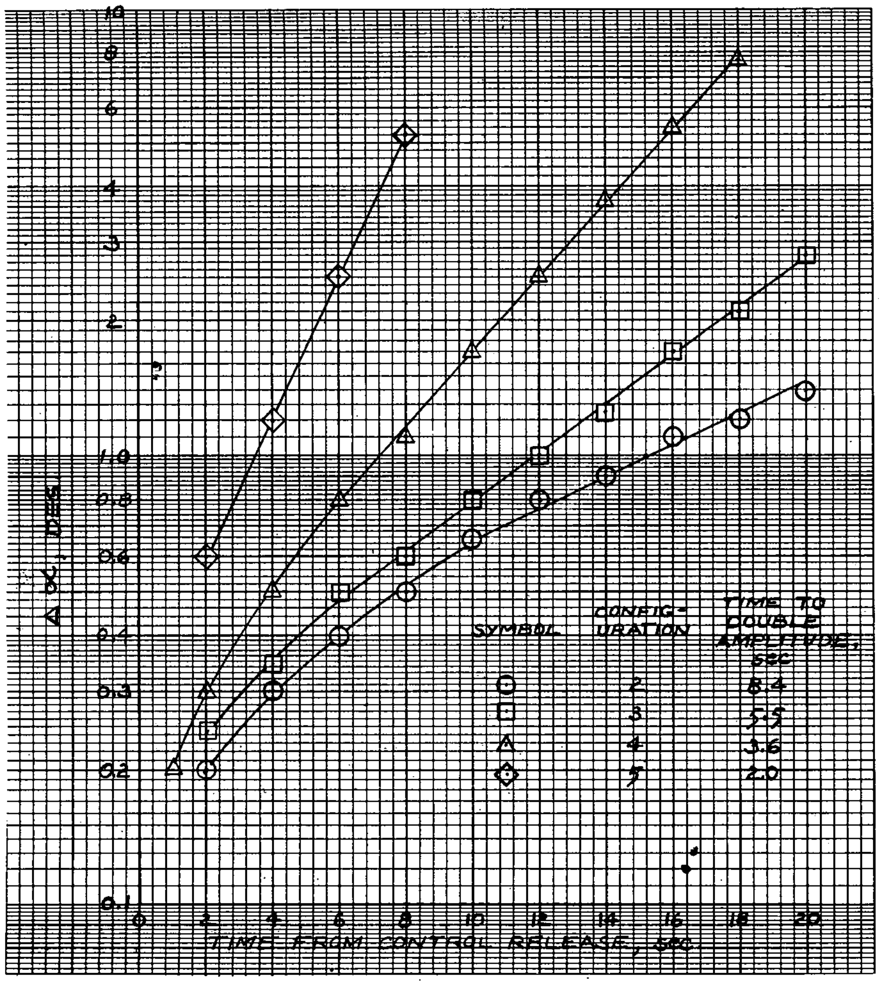


(d.) Effect of varying drag characteristics
Config 4: $d\gamma/dV = 0.106$ ("backside")
Config 11: $d\gamma/dV = 0$

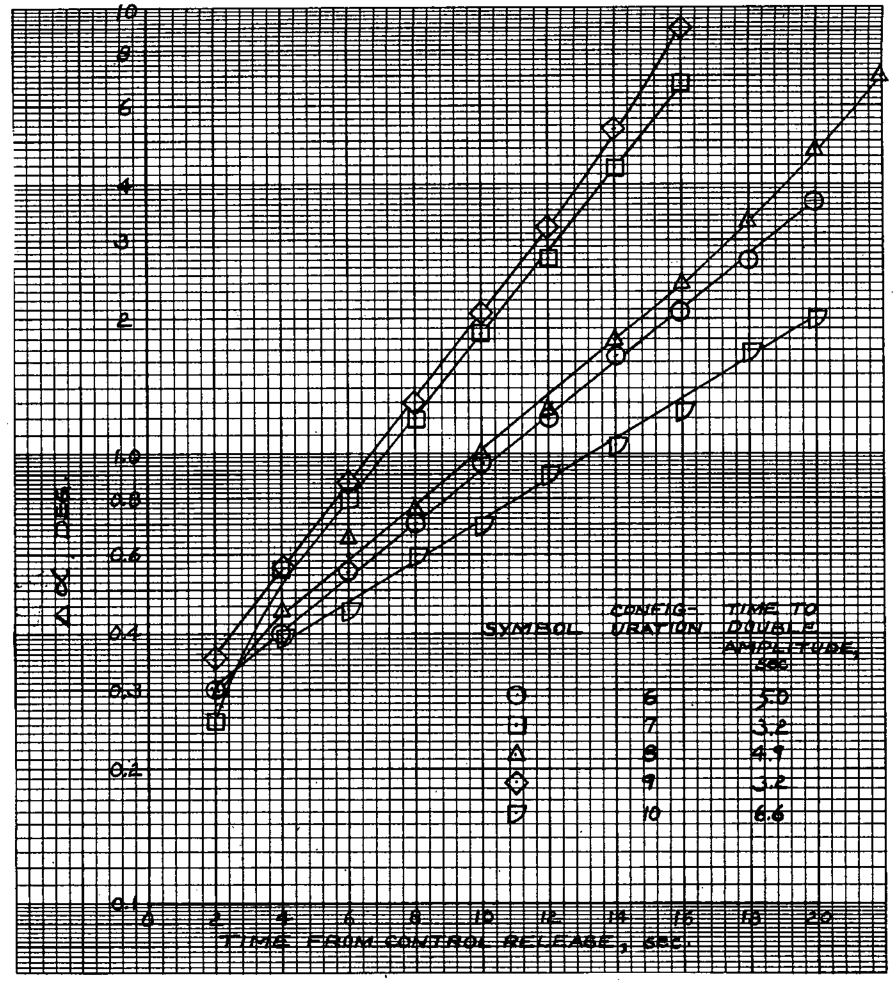


(e.) Effect of increased pitch damping with same T_2 . ($C_{m_q} + C_{m_{\dot{\alpha}}}$) for config 18 was 5 times that of config 9.

Figure 13.- Concluded.

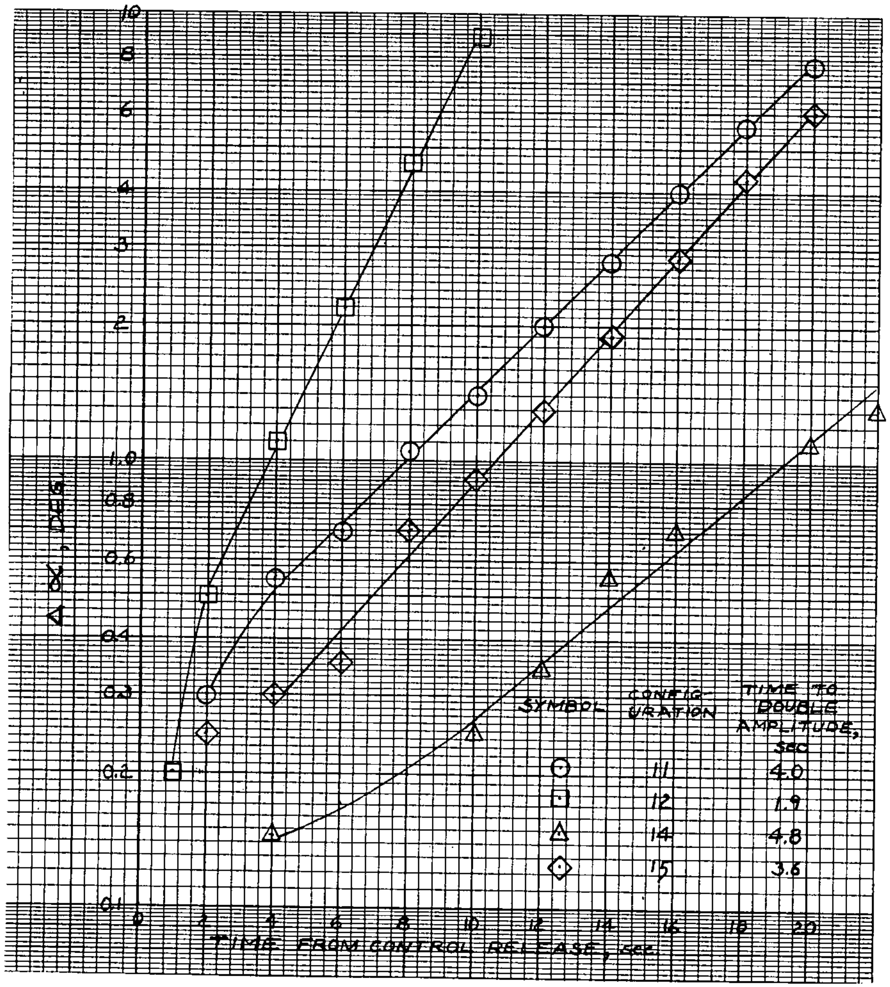


(a.) TIFS configurations 2 - 5.

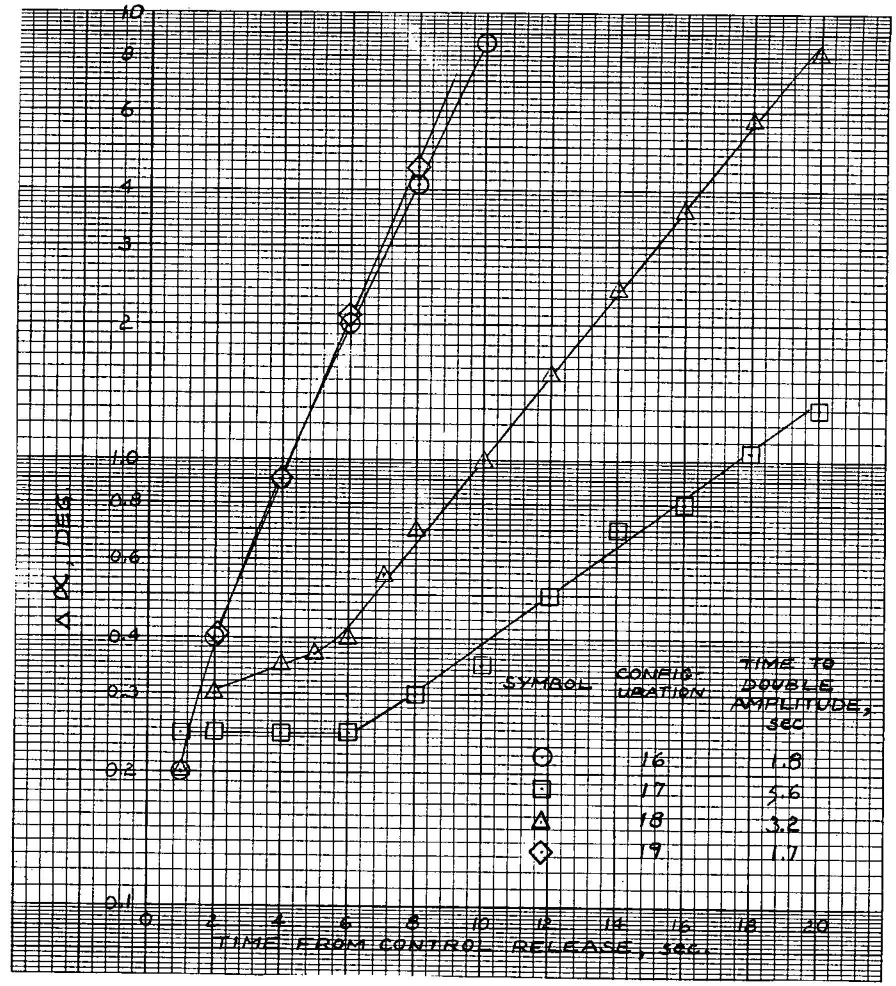


(b.) TIFS configurations 6 - 10.

Figure 14.- Work-sheet for determination of measured time to double amplitude using angle of attack.

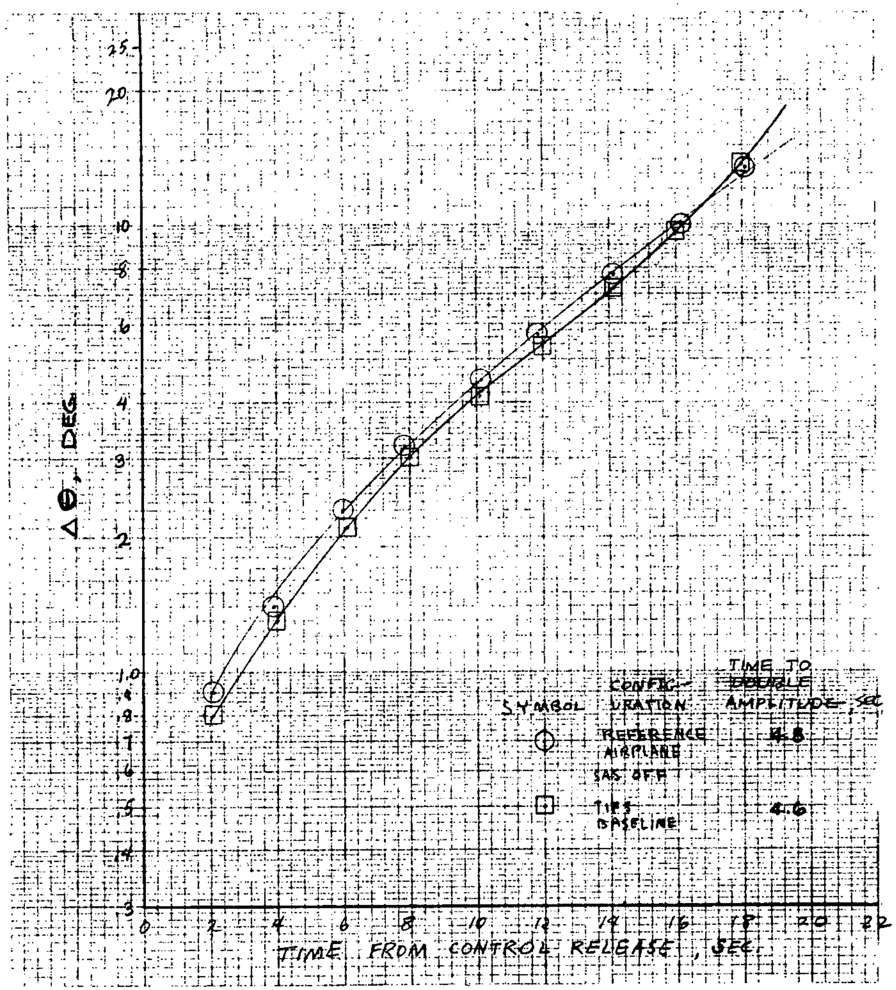


(c.) TIFS configurations 11, 12, 14 and 15.

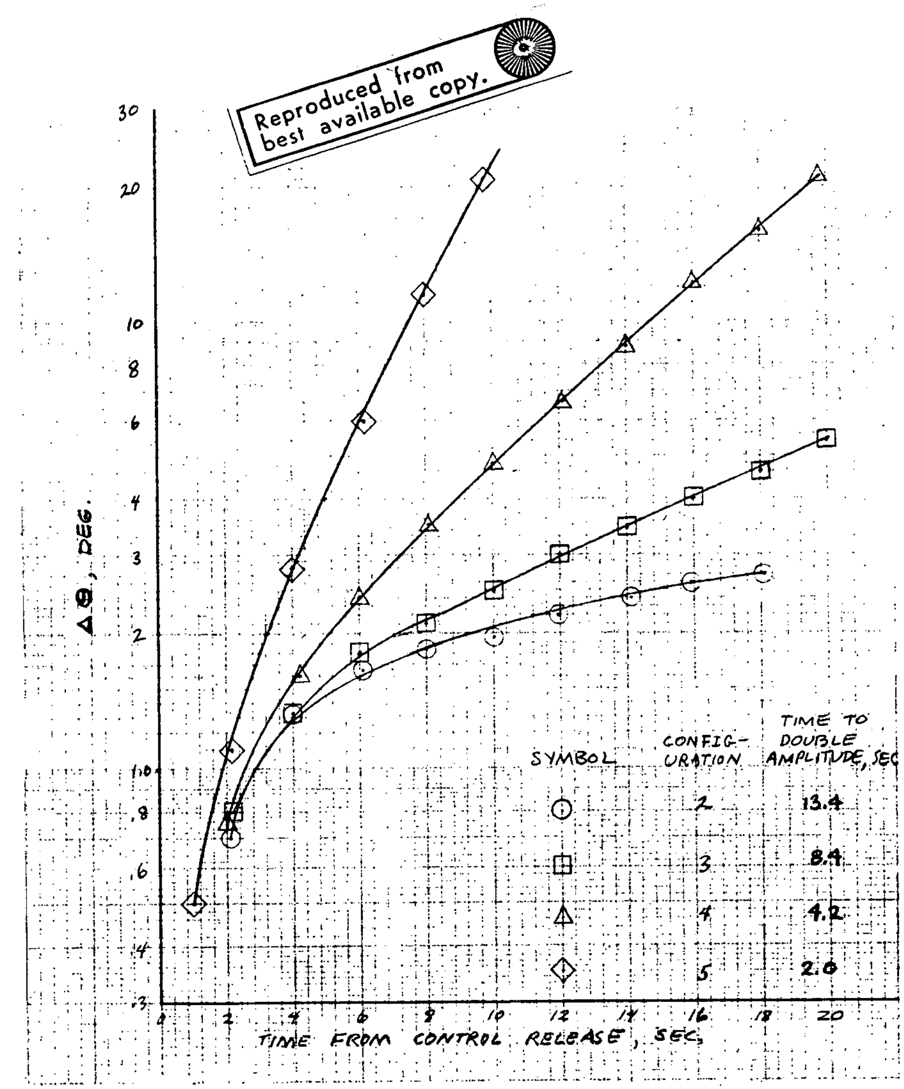


(d.) TIFS configurations 16 - 19.

Figure 14.- Concluded.

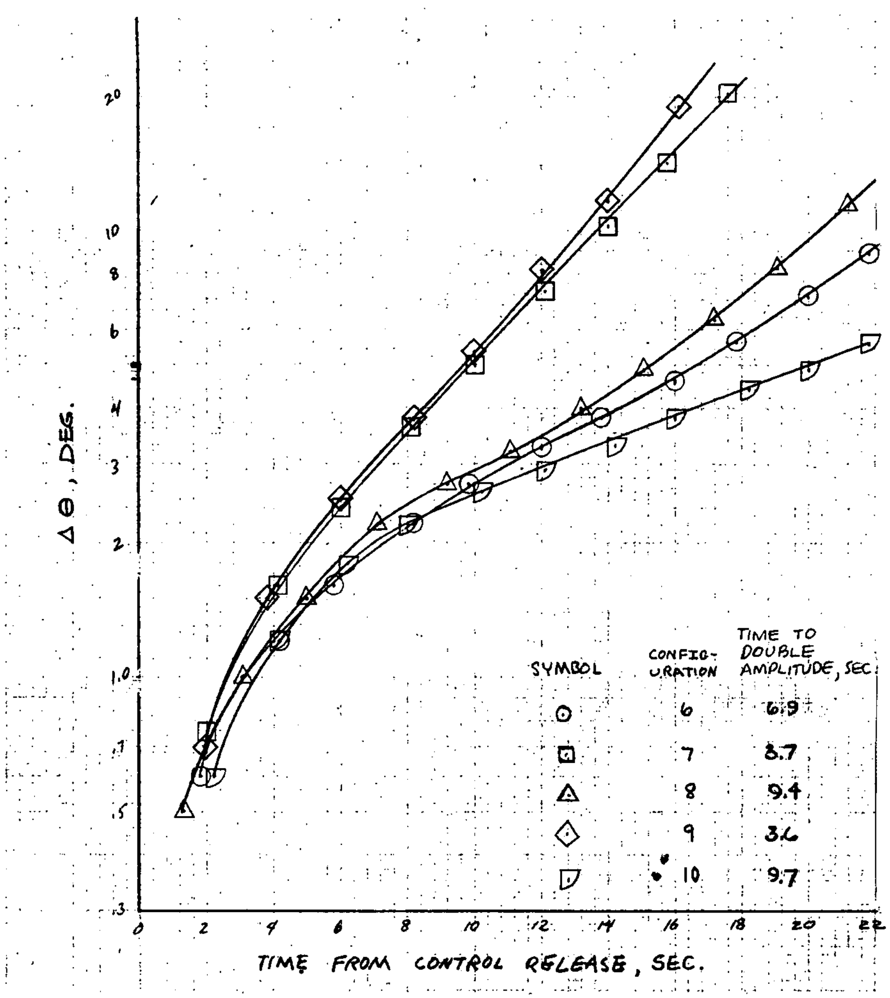


(a.) TIFS baseline and unaugmented ref. airplane.

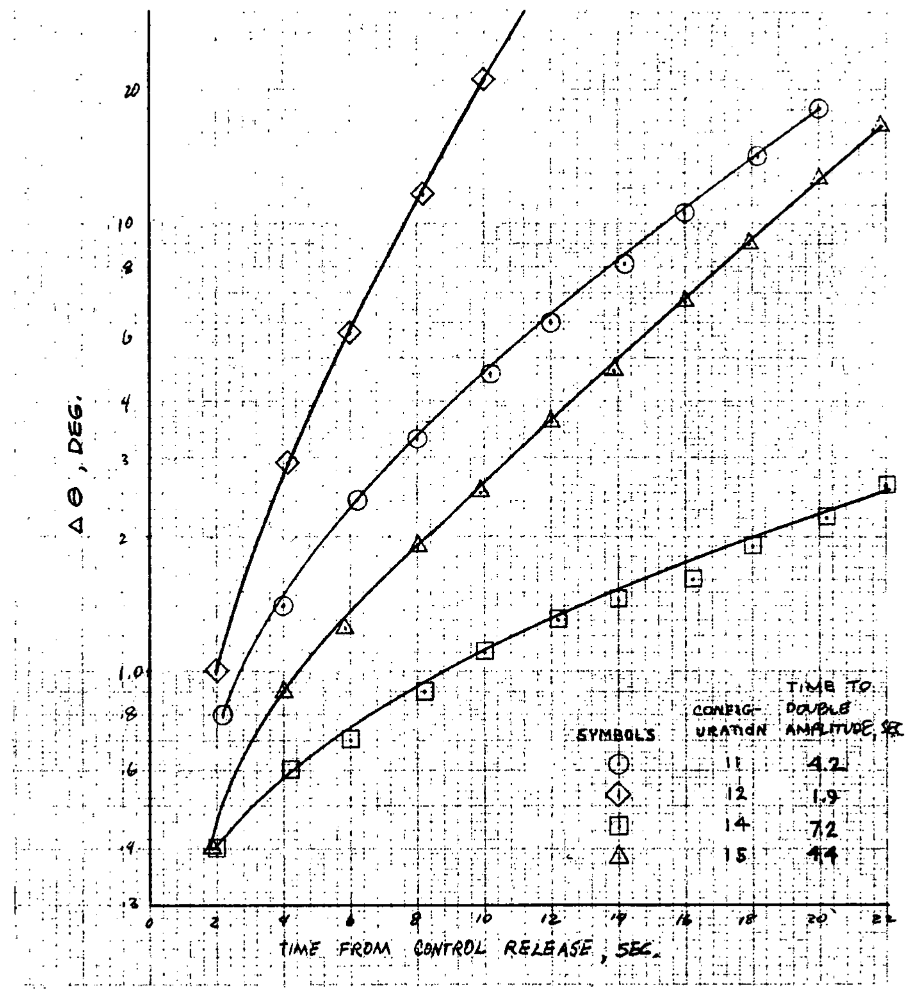


(b.) TIFS configurations 2 - 5.

Figure 15.- Work-sheet for determination of measured time to double amplitude using pitch attitude.

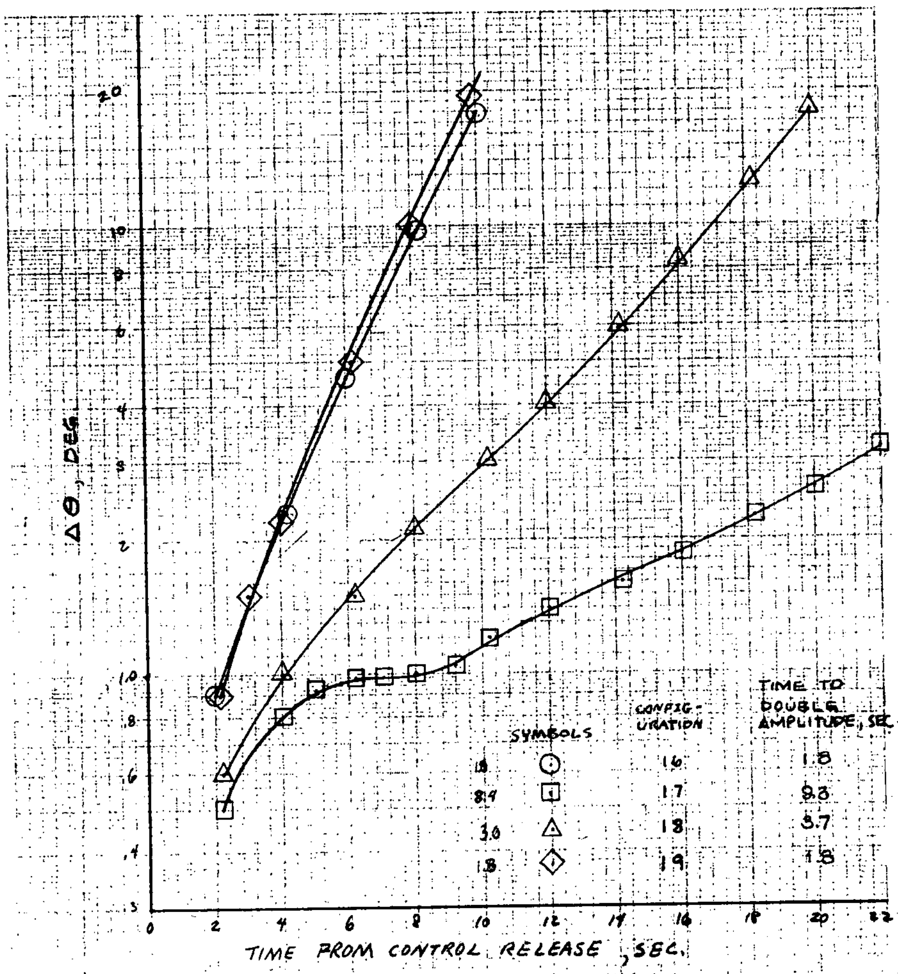


(c.) TIFS configurations 6 - 10.



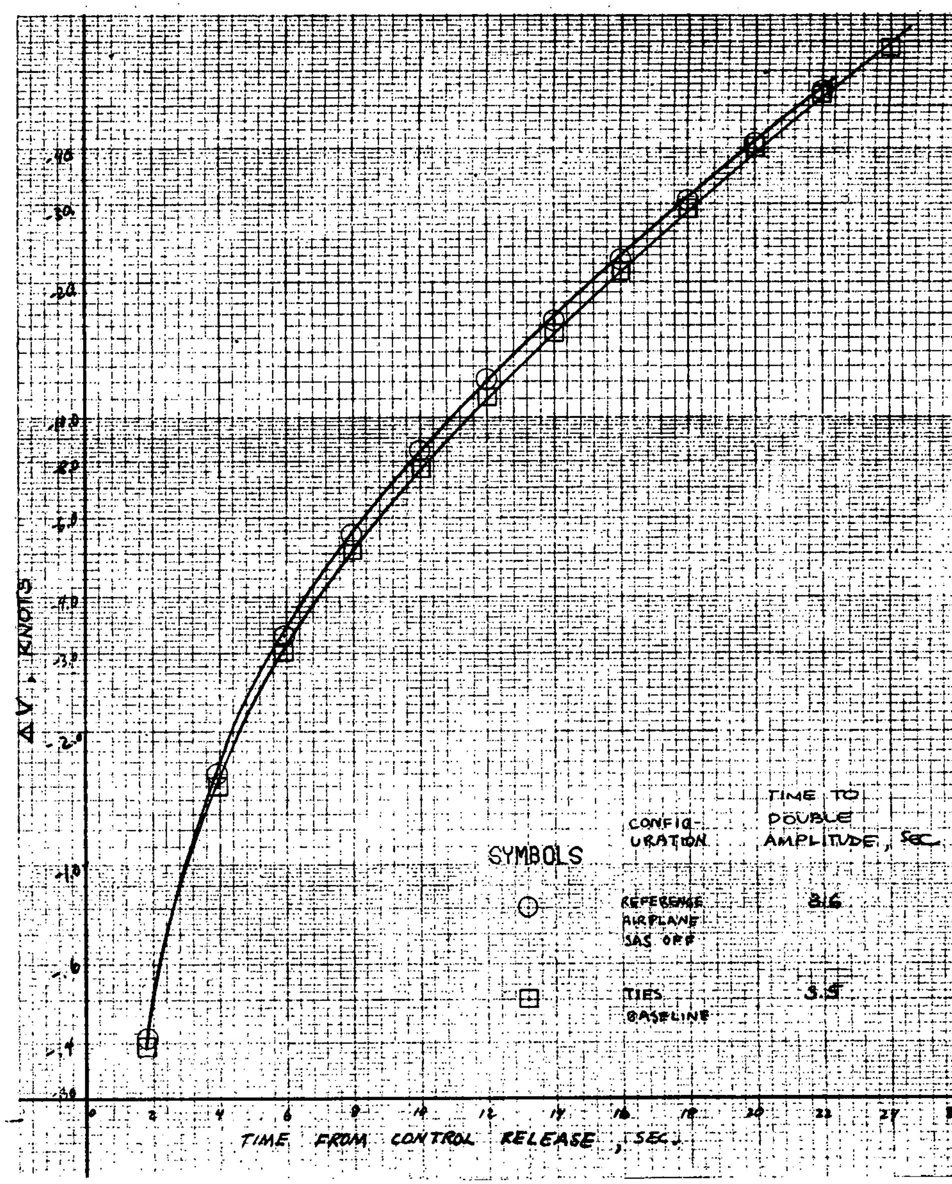
(d.) TIFS configurations 11, 12, 14 and 15.

Figure 15.- Continued



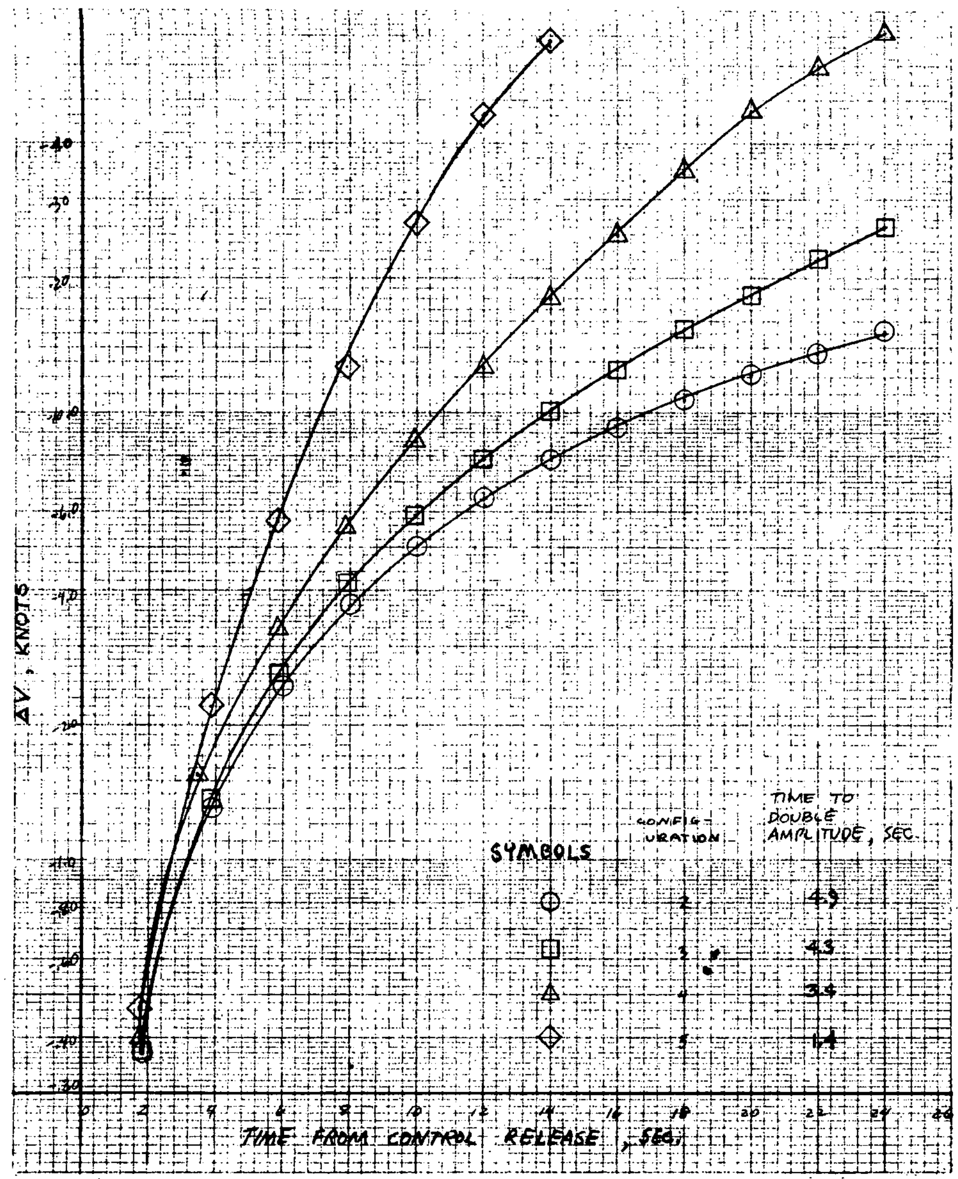
(e.) TIFS configurations 16 -19.

Figure 15.- Concluded

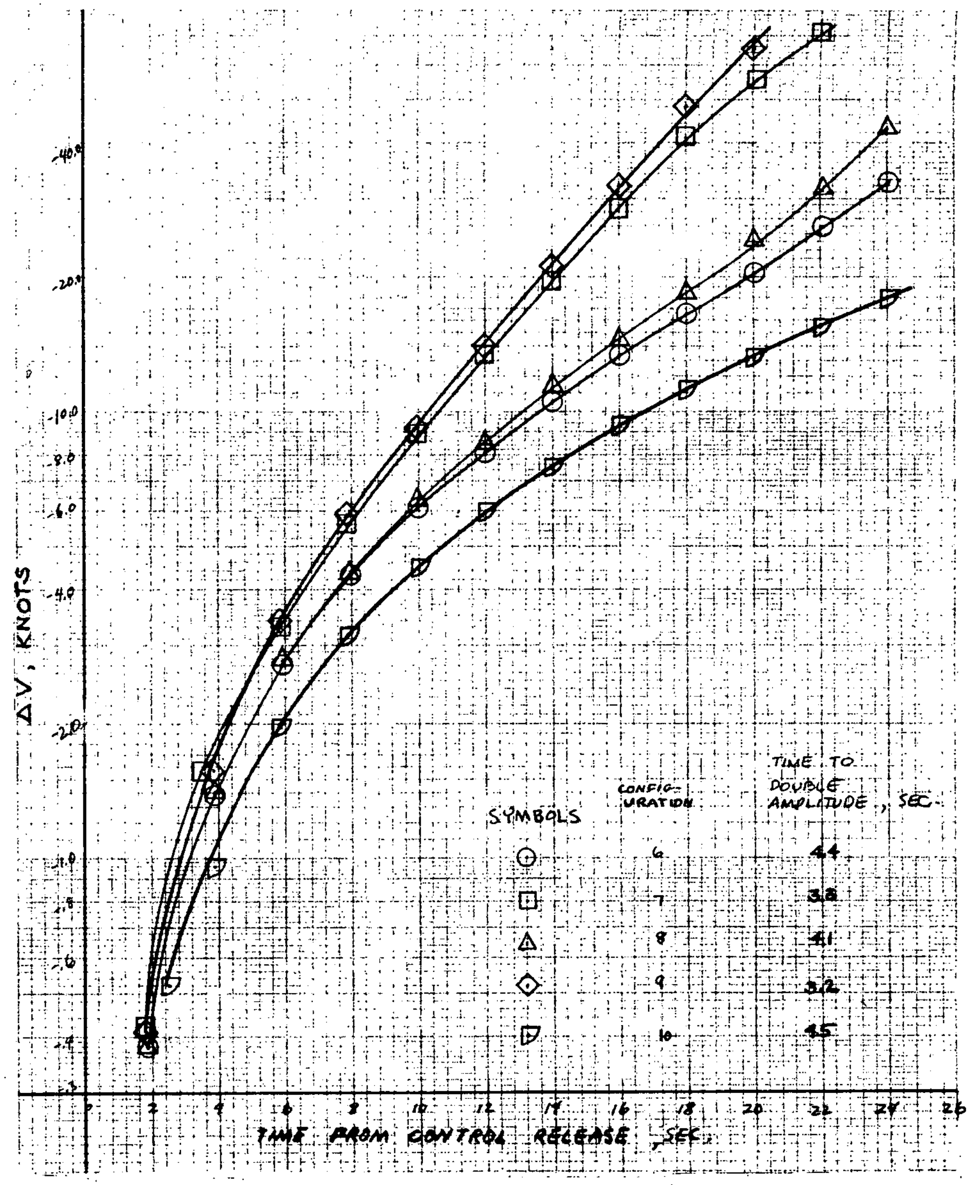


(a.) TIFS baseline and unaugmented ref. airplane.

Figure 16.- Work-sheet for determination of measured time to double amplitude using calibrated airspeed.

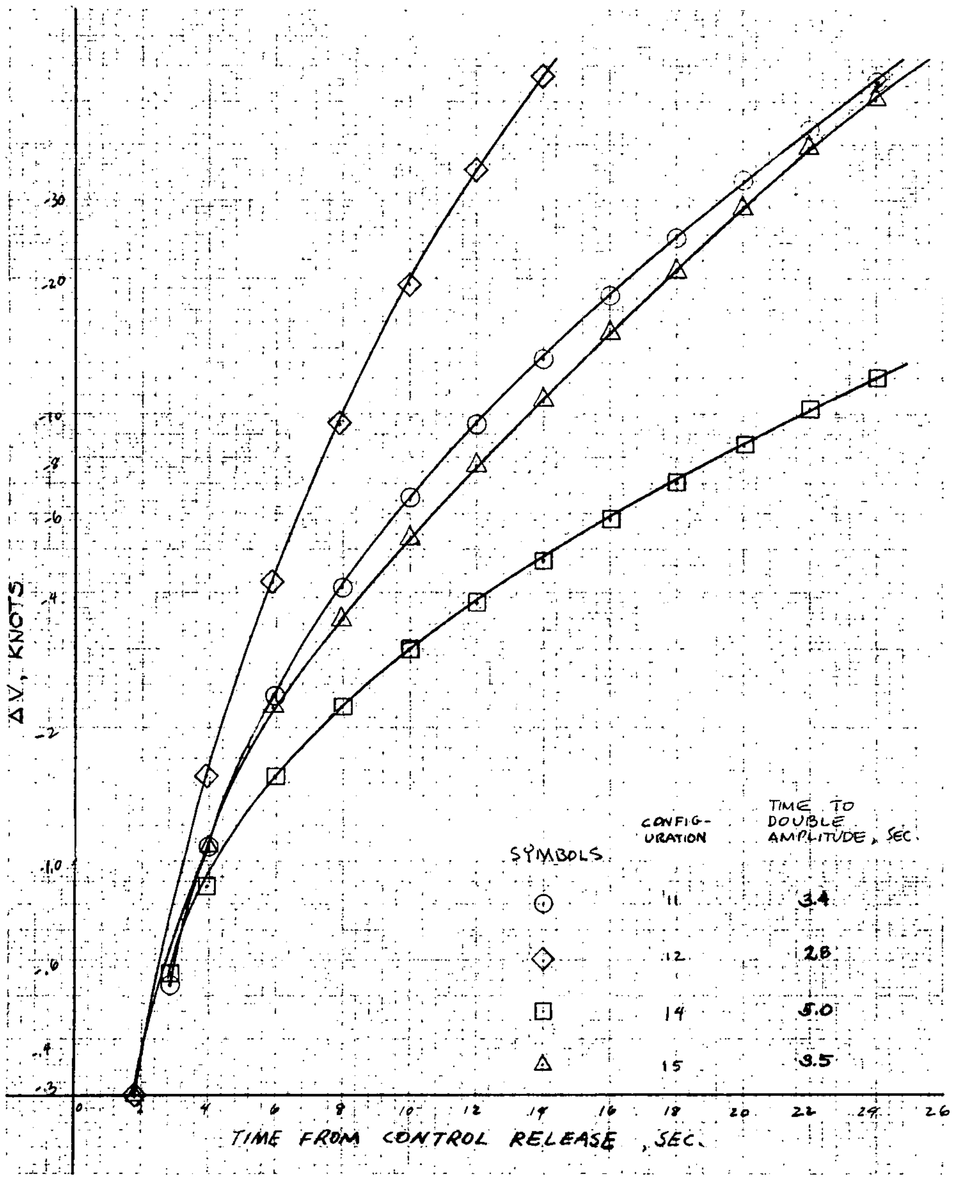


(b.) TIFS configurations 2 - 5.

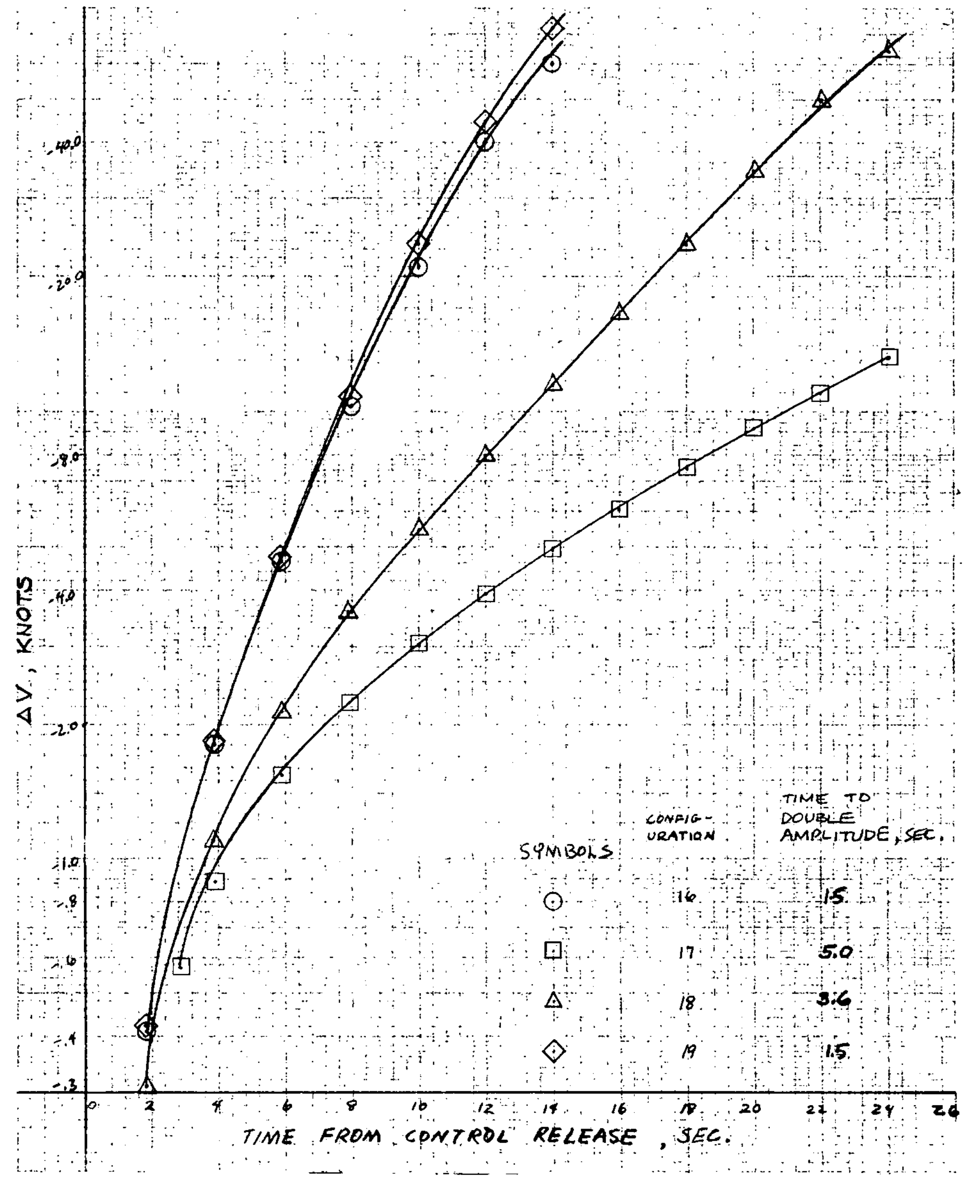


(c.) TIFS configurations 6 - 10.

Figure 16.- Continued

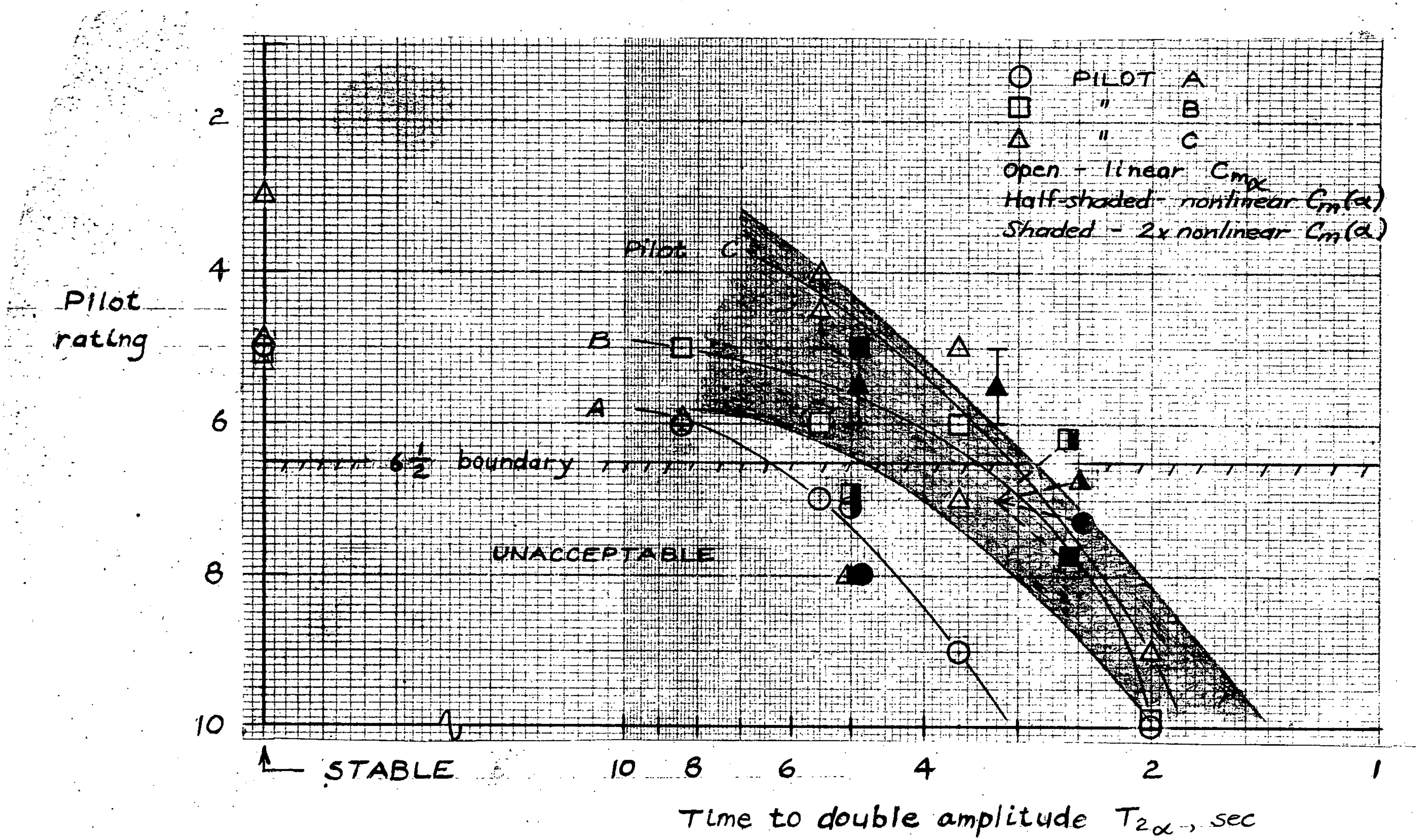


(d.) TIFS configurations 11, 12, 14 and 15.



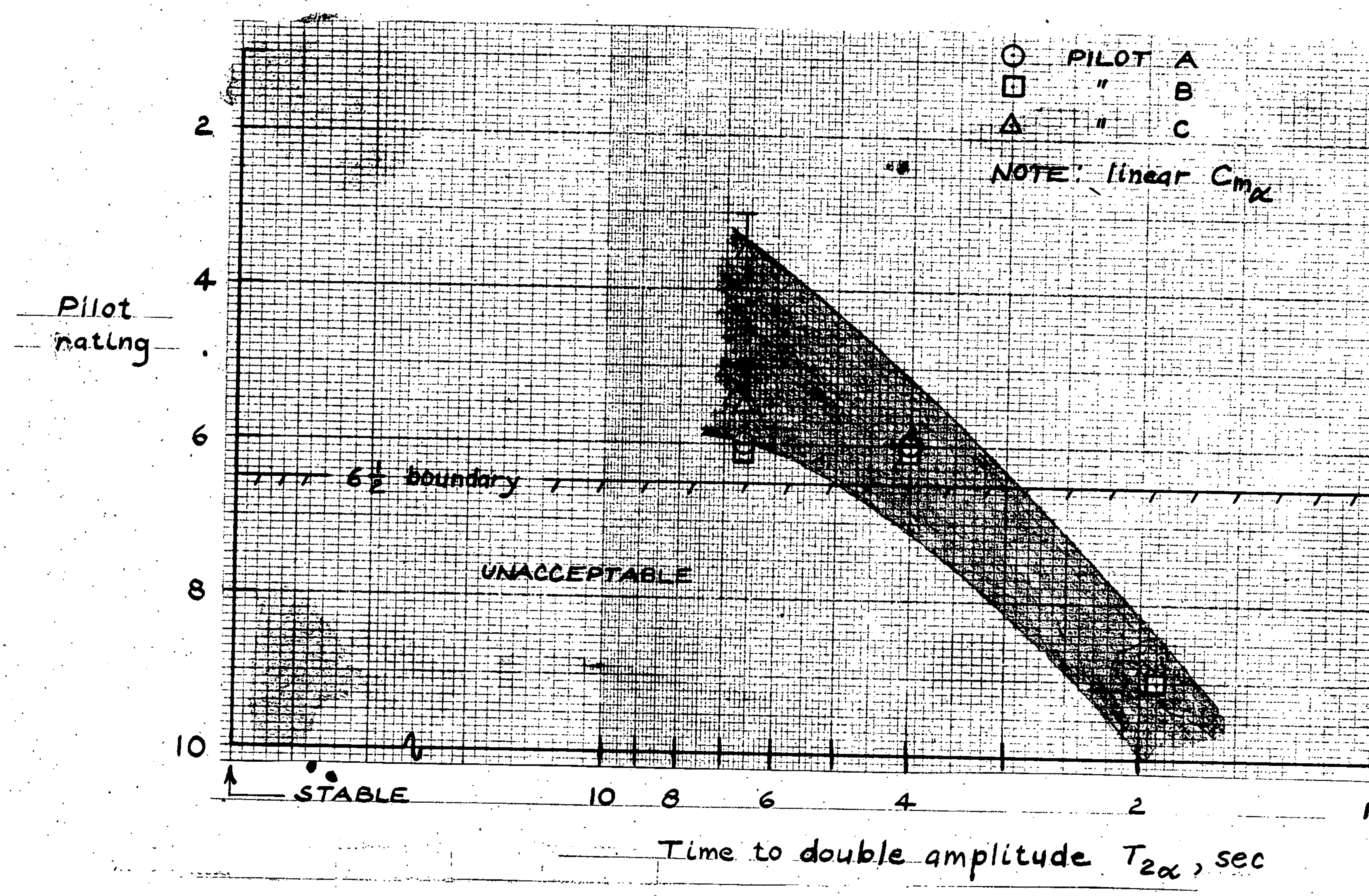
(e.) TIFS configurations 16 - 19.

Figure 16.- Concluded



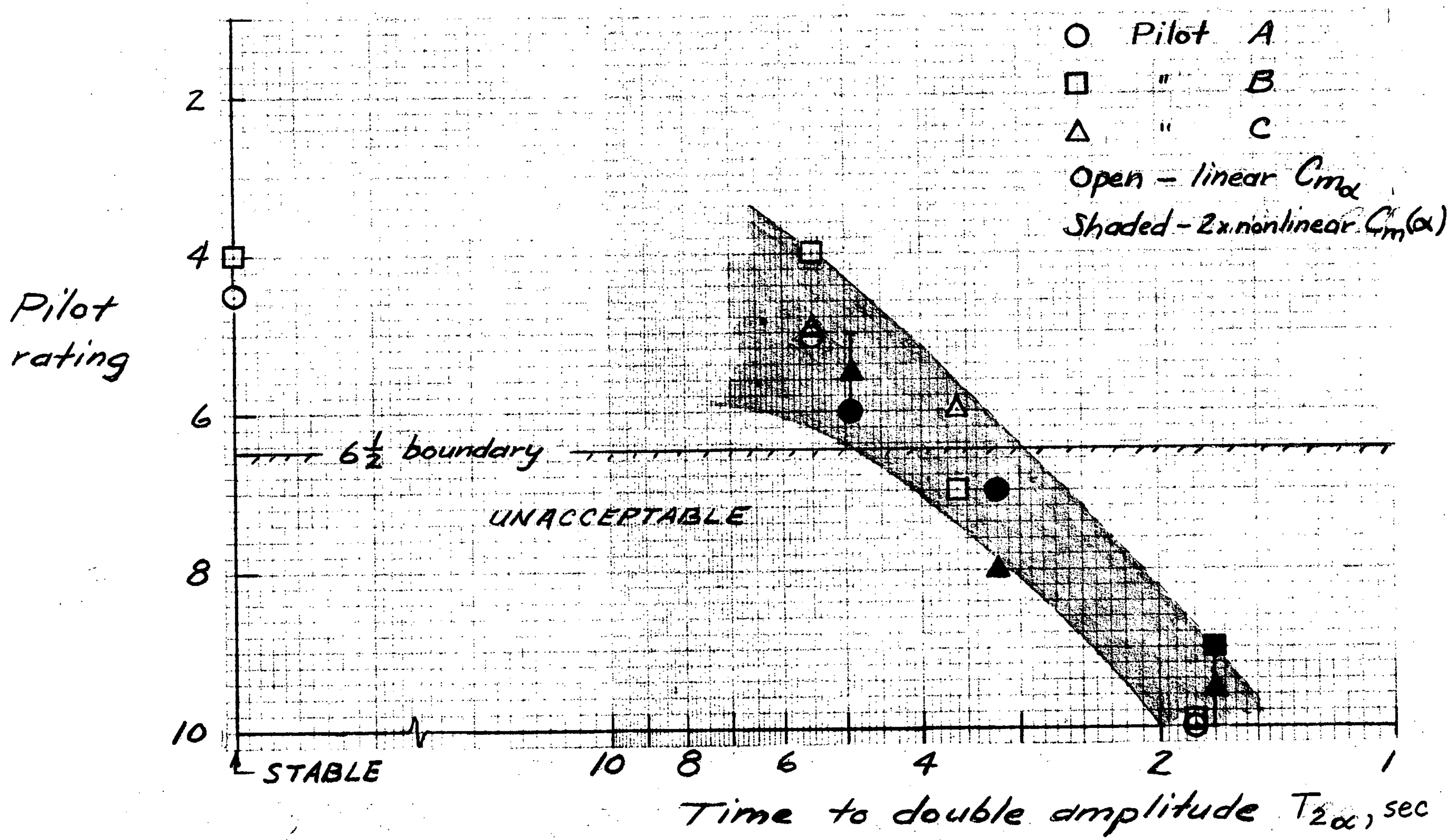
(a.) Normal damping and "backside" of drag curve (configurations 1 - 9)

Figure 17.- Pilot rating versus time to double amplitude.



(b.) Normal damping and $d\gamma/dV = 0$ (configurations 10 - 12)

Figure 17.- Continued



(c.) 5 x normal damping and "backside" of drag curve (configurations 13 - 19)

Figure 17.- Concluded.

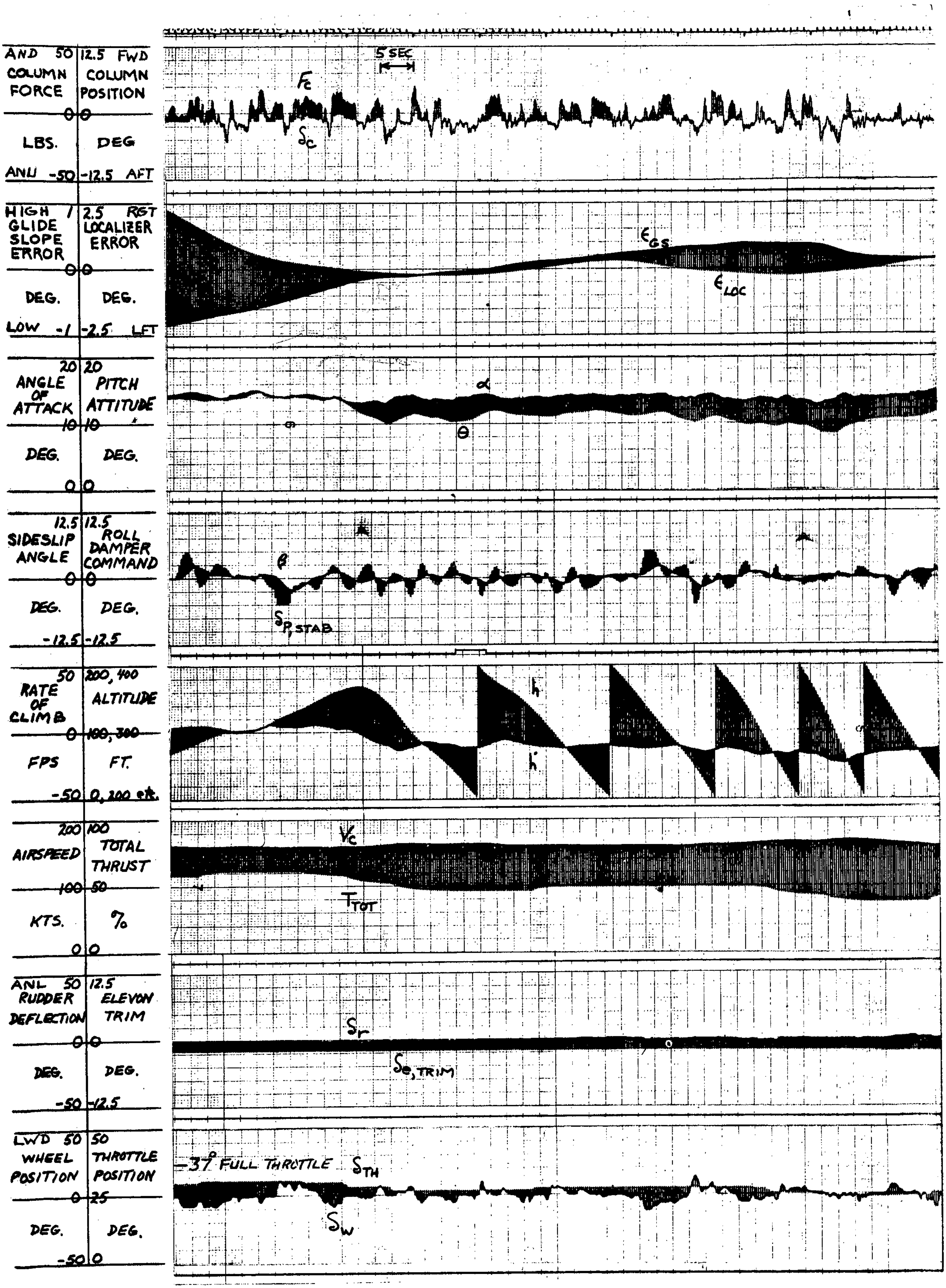


Figure 18.- IFR portion of landing approach Task B for configuration 15 (T_{2_α} = 3.6 sec)

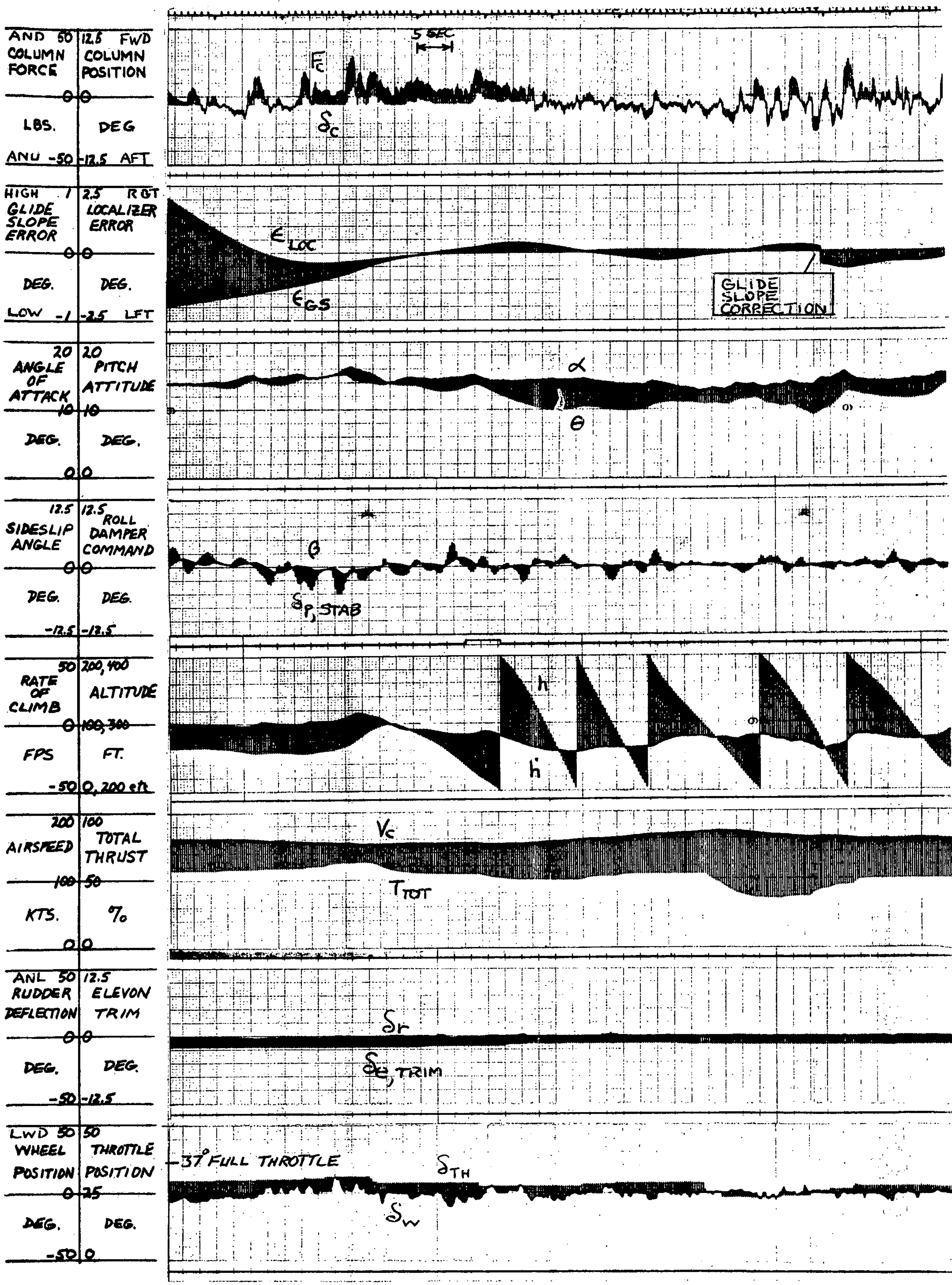


Figure 19.- IFR portion of landing approach Task C for configuration 15 (T_{2_α} = 3.6 sec)

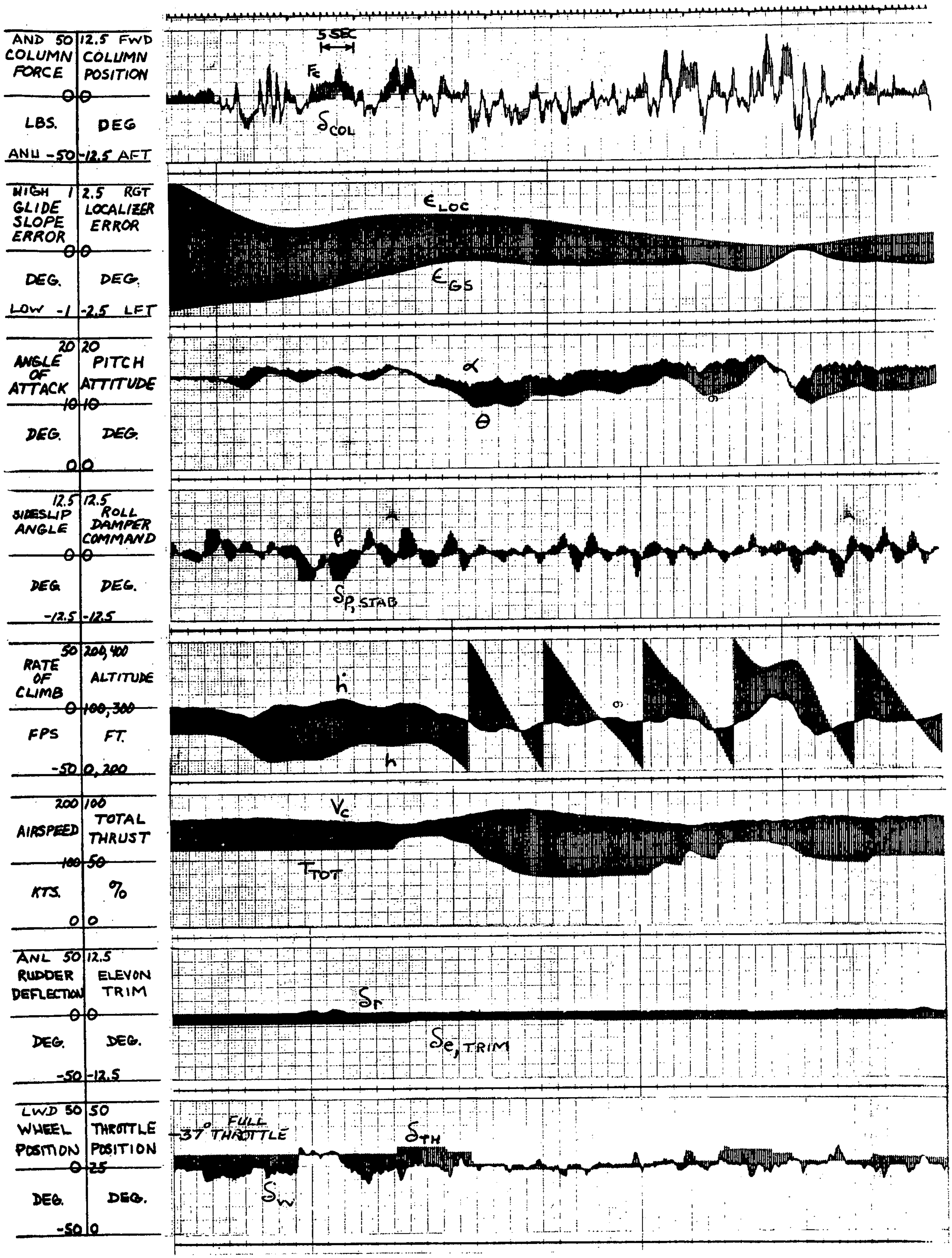


Figure 20.- IFR portion of landing approach Task D for configuration 15 (T_{2_α} = 3.6 sec)

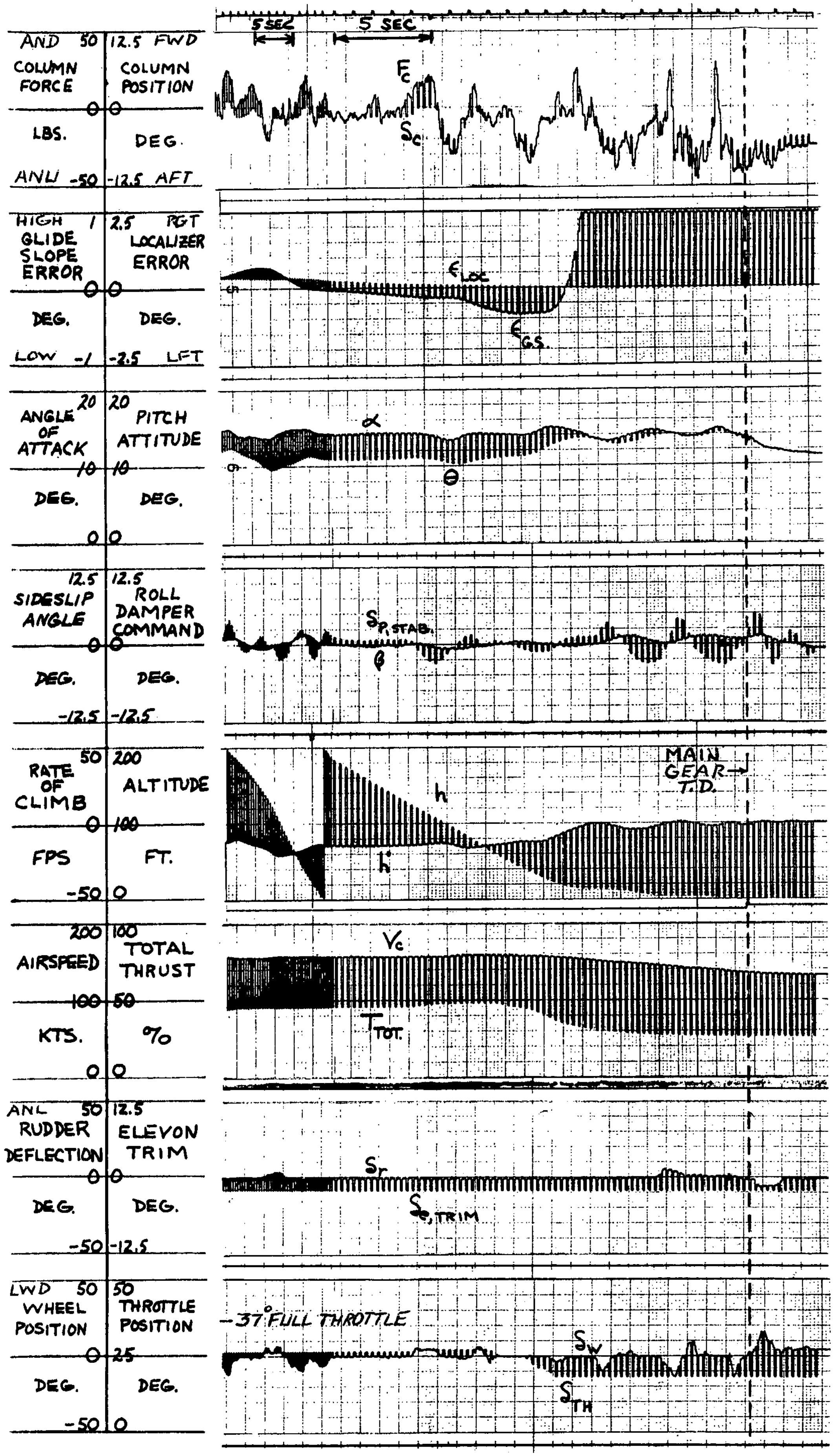


Figure 21.- VFR portion of landing approach Task B for configuration 15 (T_{2_α} = 3.6 sec)

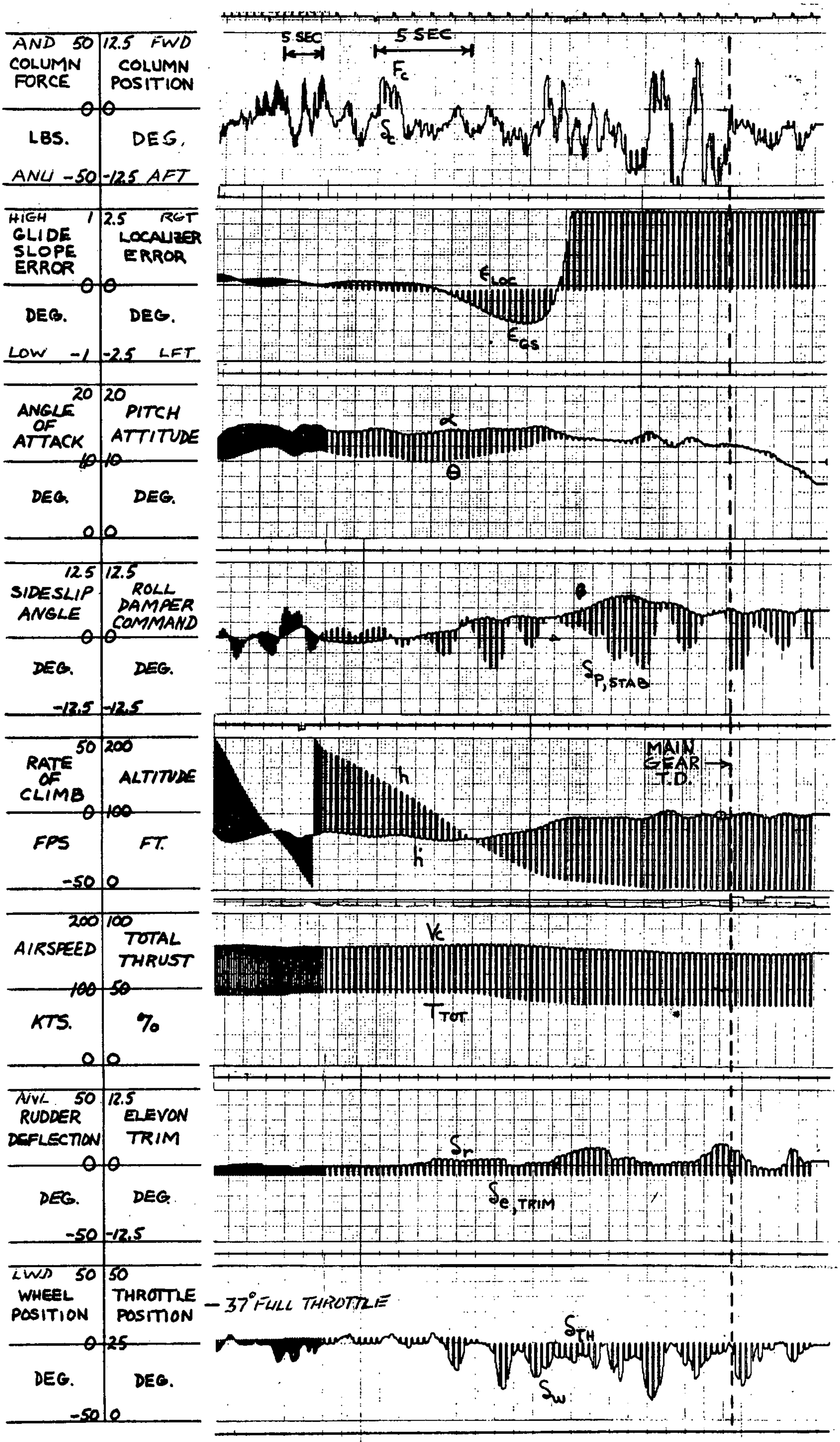


Figure 22.- VFR portion of landing approach Task C for configuration 15 (T_{2_α} = 3.6 sec)

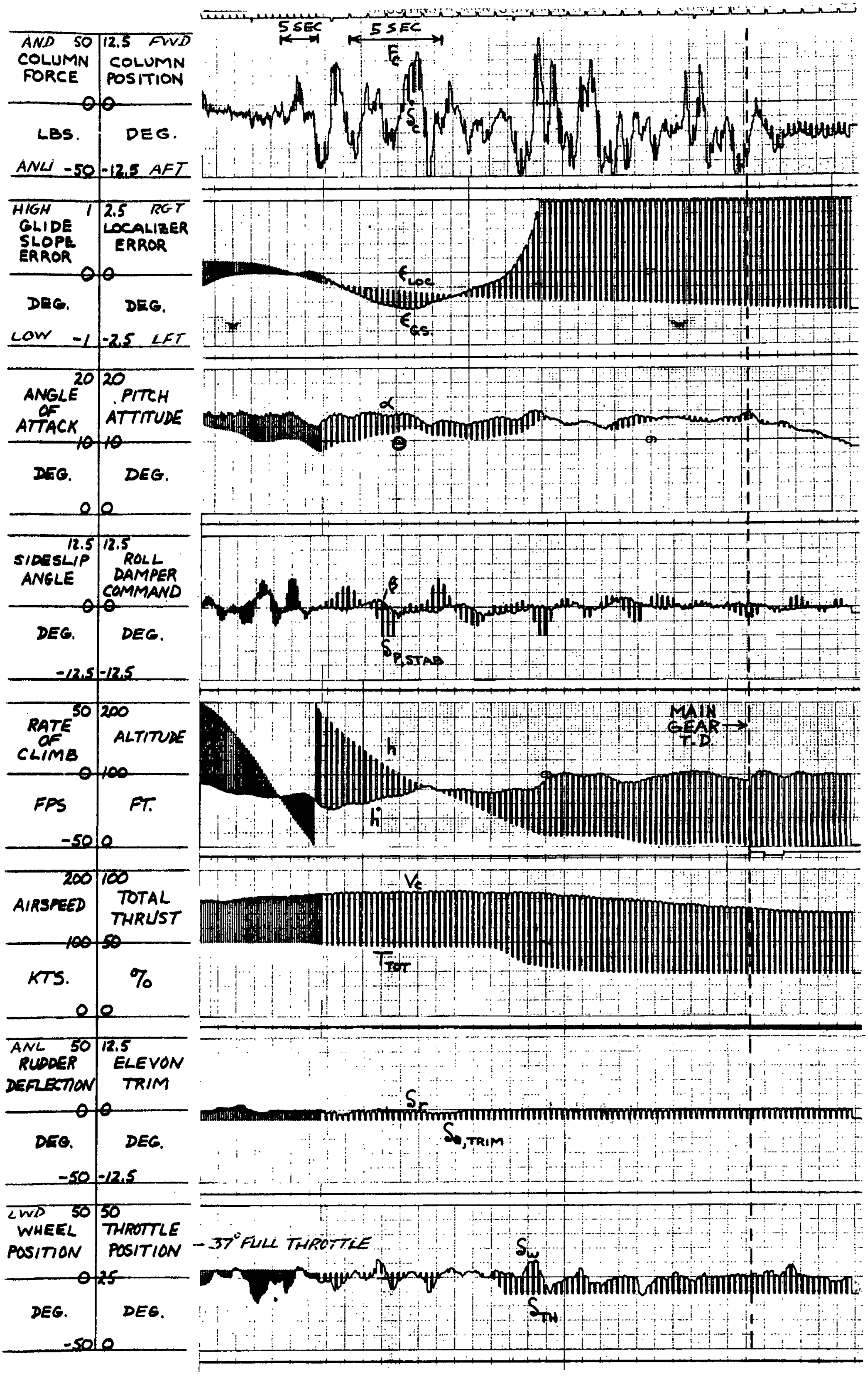


Figure 23.- VFR portion of landing approach Task D for configuration 15 (T_{2_α} = 3.6 sec)

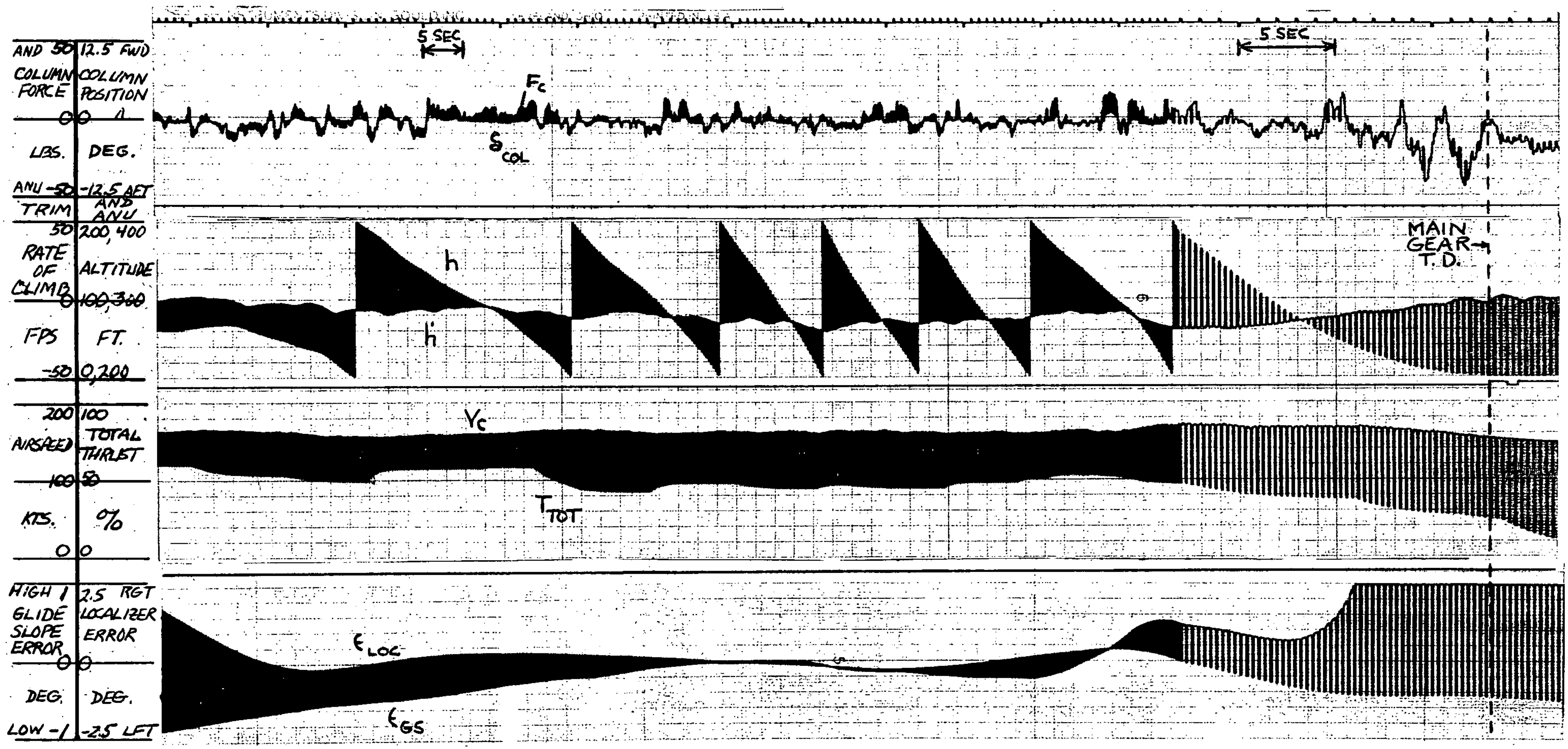


Figure 24.- Control characteristics during landing approach Task D for reference airplane with augmentation.

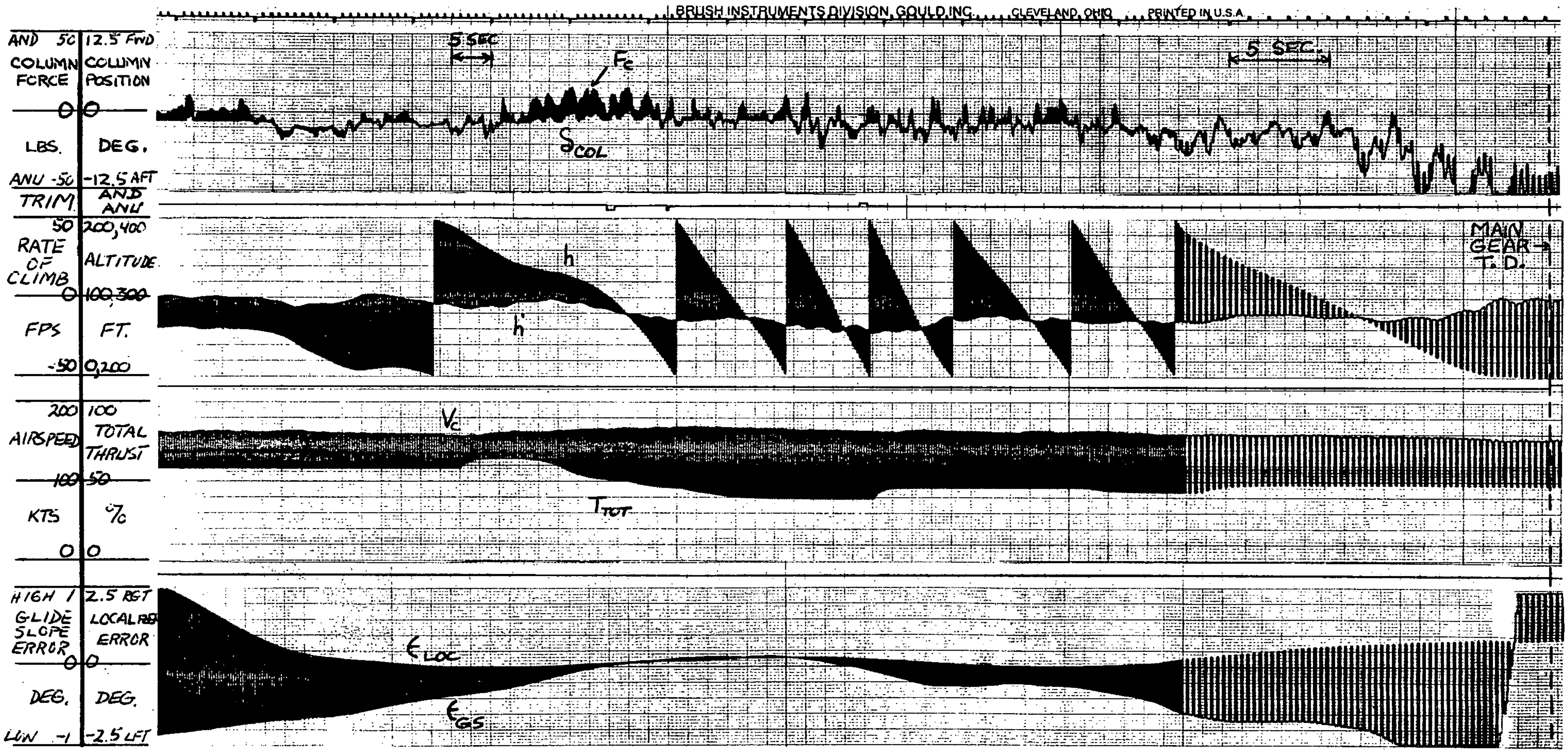


Figure 25.- Control characteristics during landing approach Task D for configuration 1 (stable).

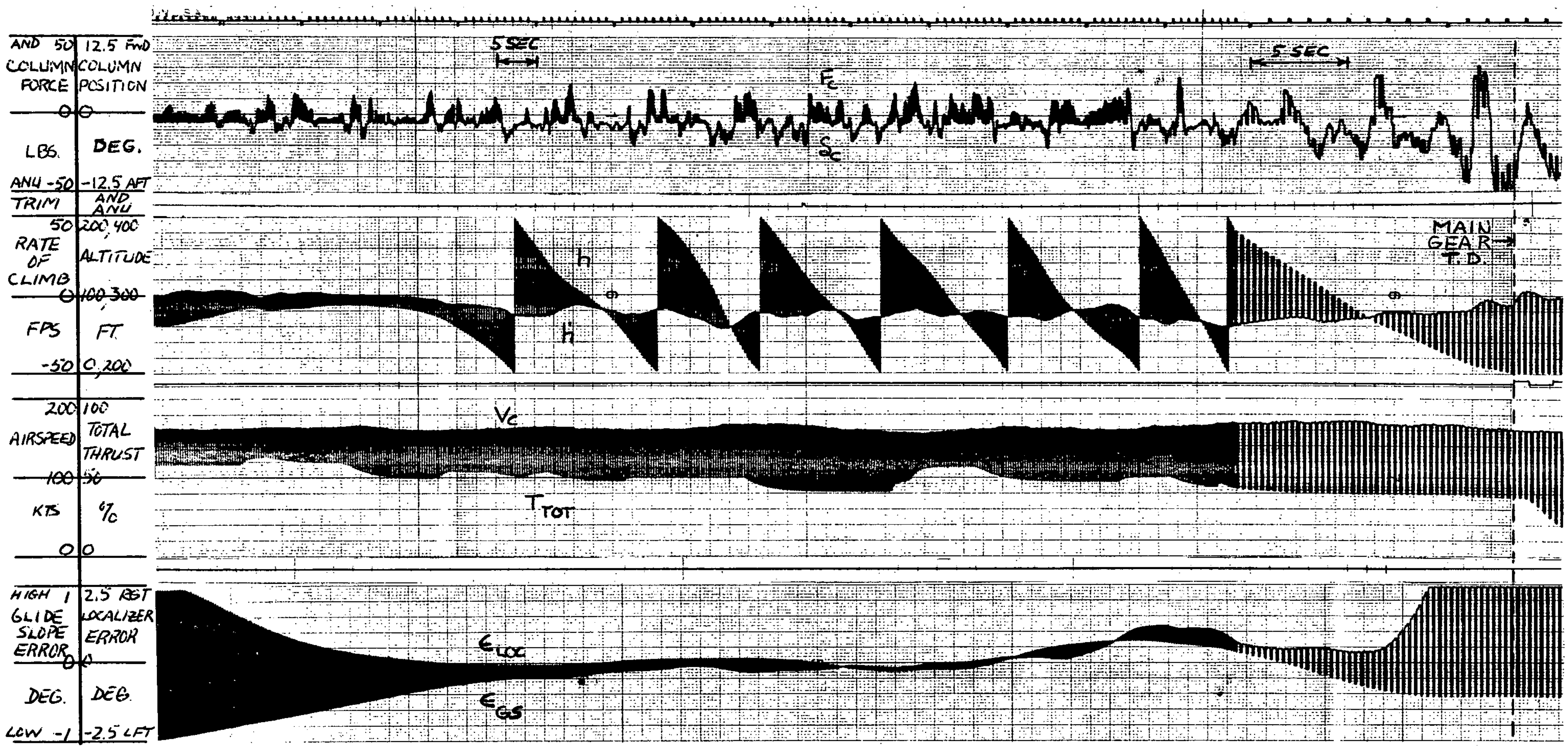


Figure 26.- Control characteristics during landing approach Task D for configuration 4 (T_{2_α} = 3.6 sec).

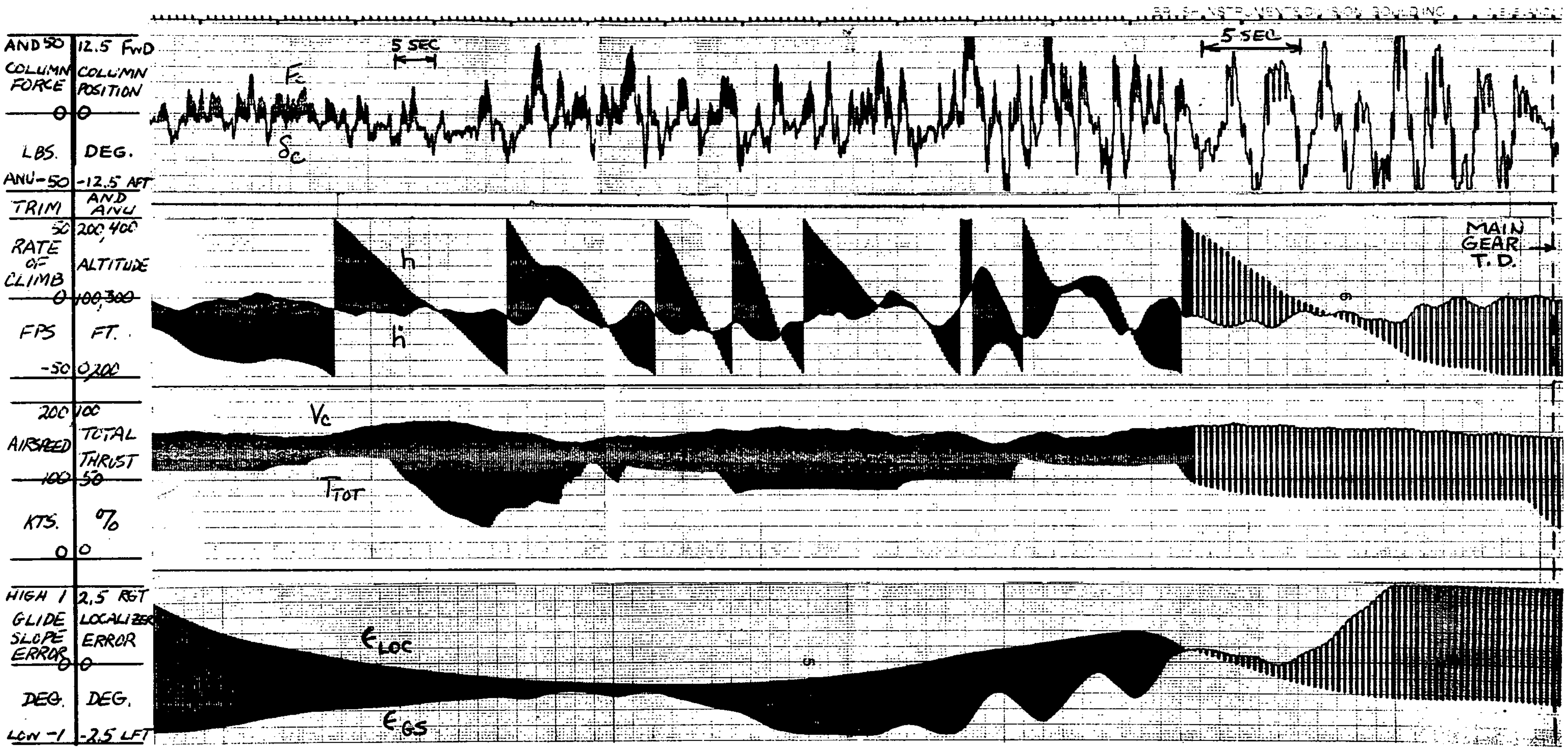


Figure 27.- Control characteristics during landing approach Task D for configuration 5 (T_{2_α} = 2.0 sec).

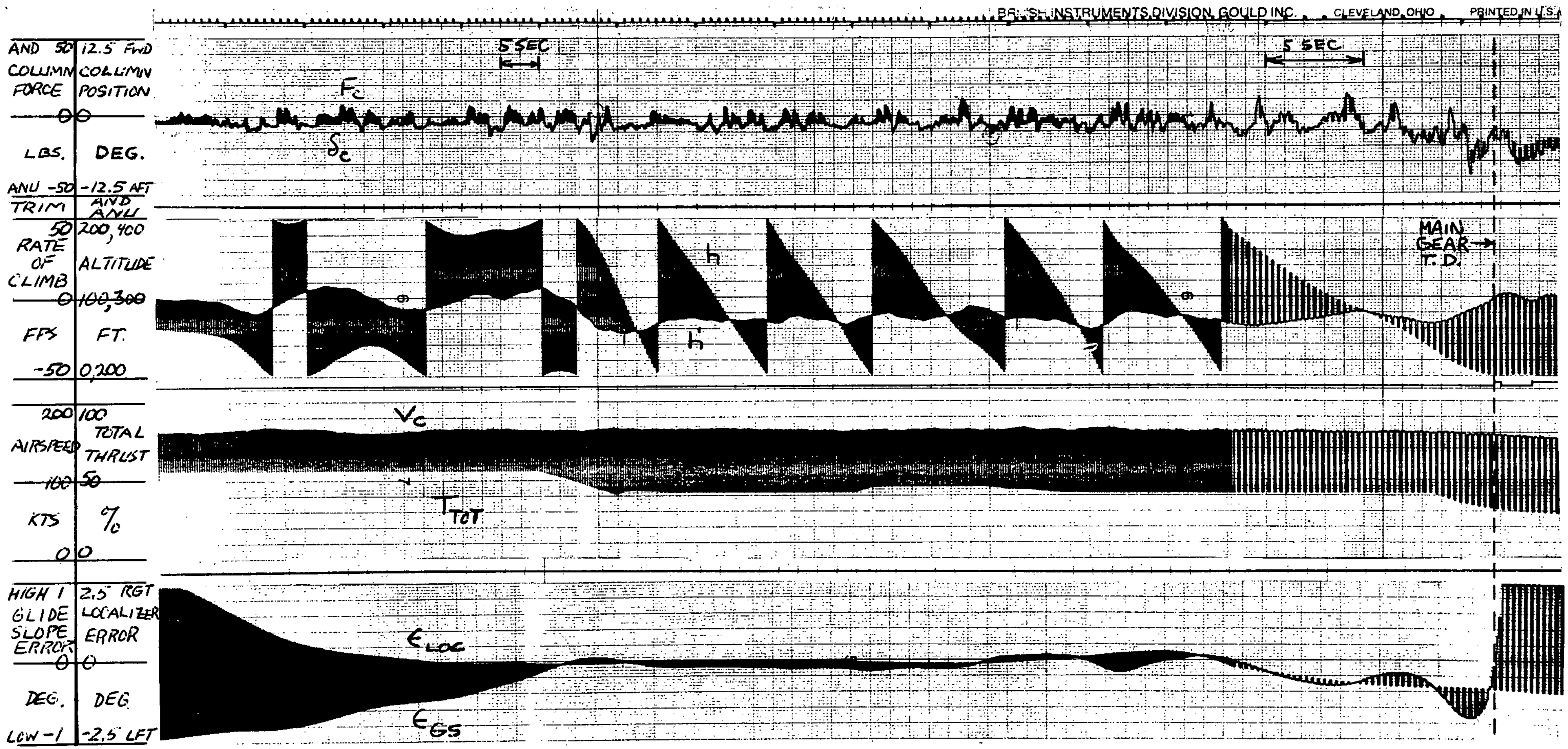
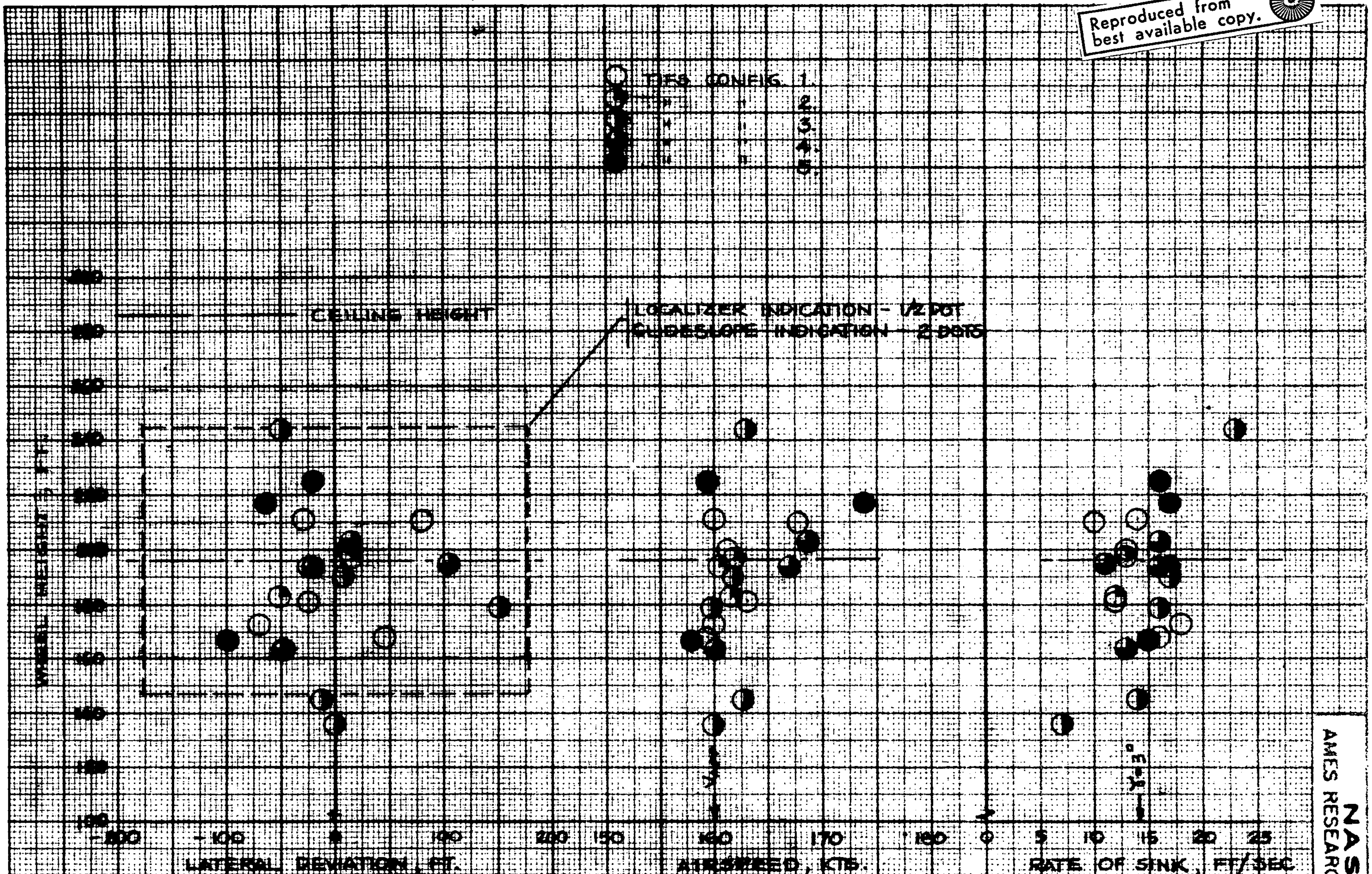
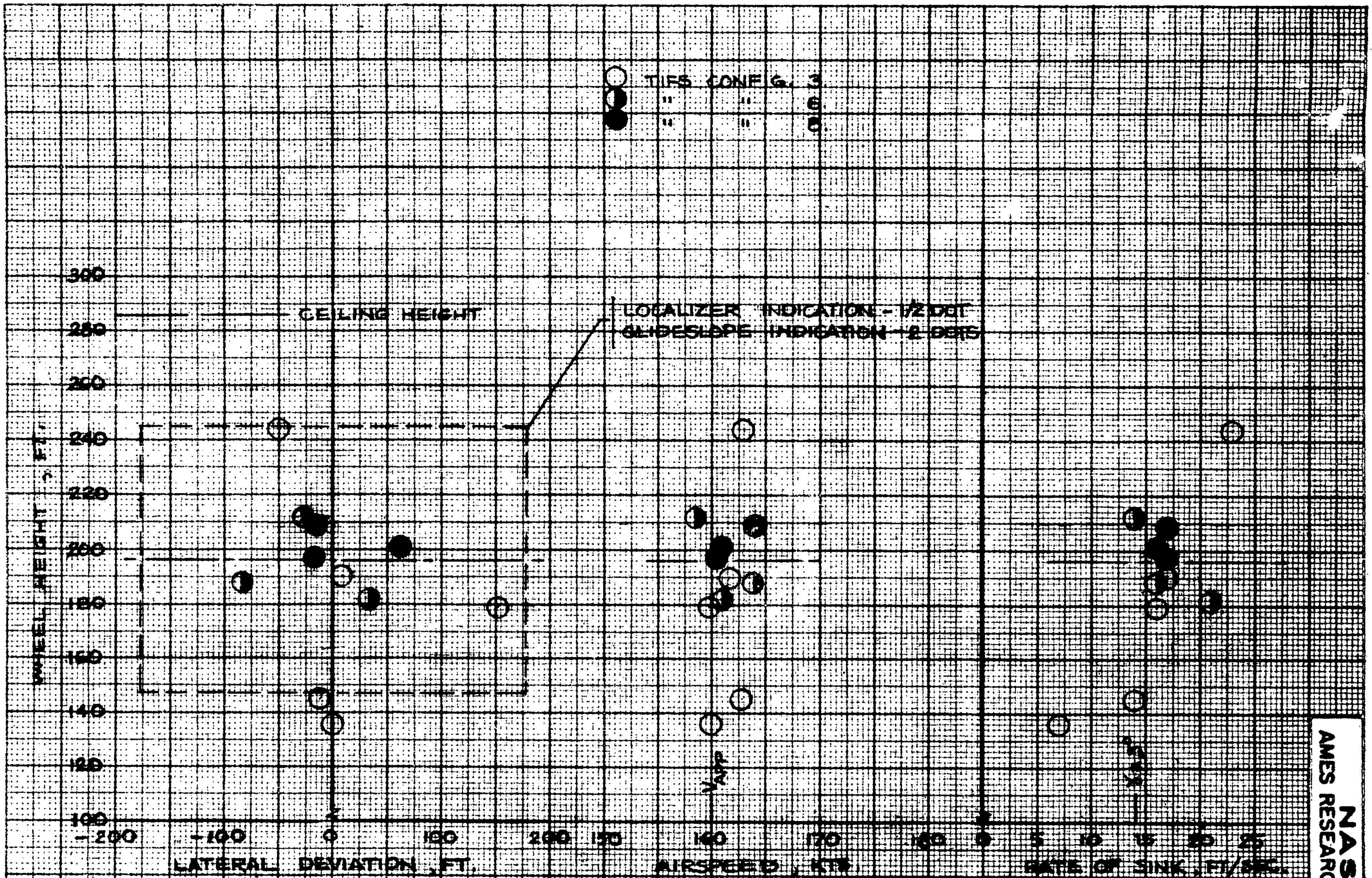


Figure 28.- Control characteristics during landing approach Task D for configuration 11 (T_{2_α} = 4.0 sec and $d\gamma/dV \cong 0$)



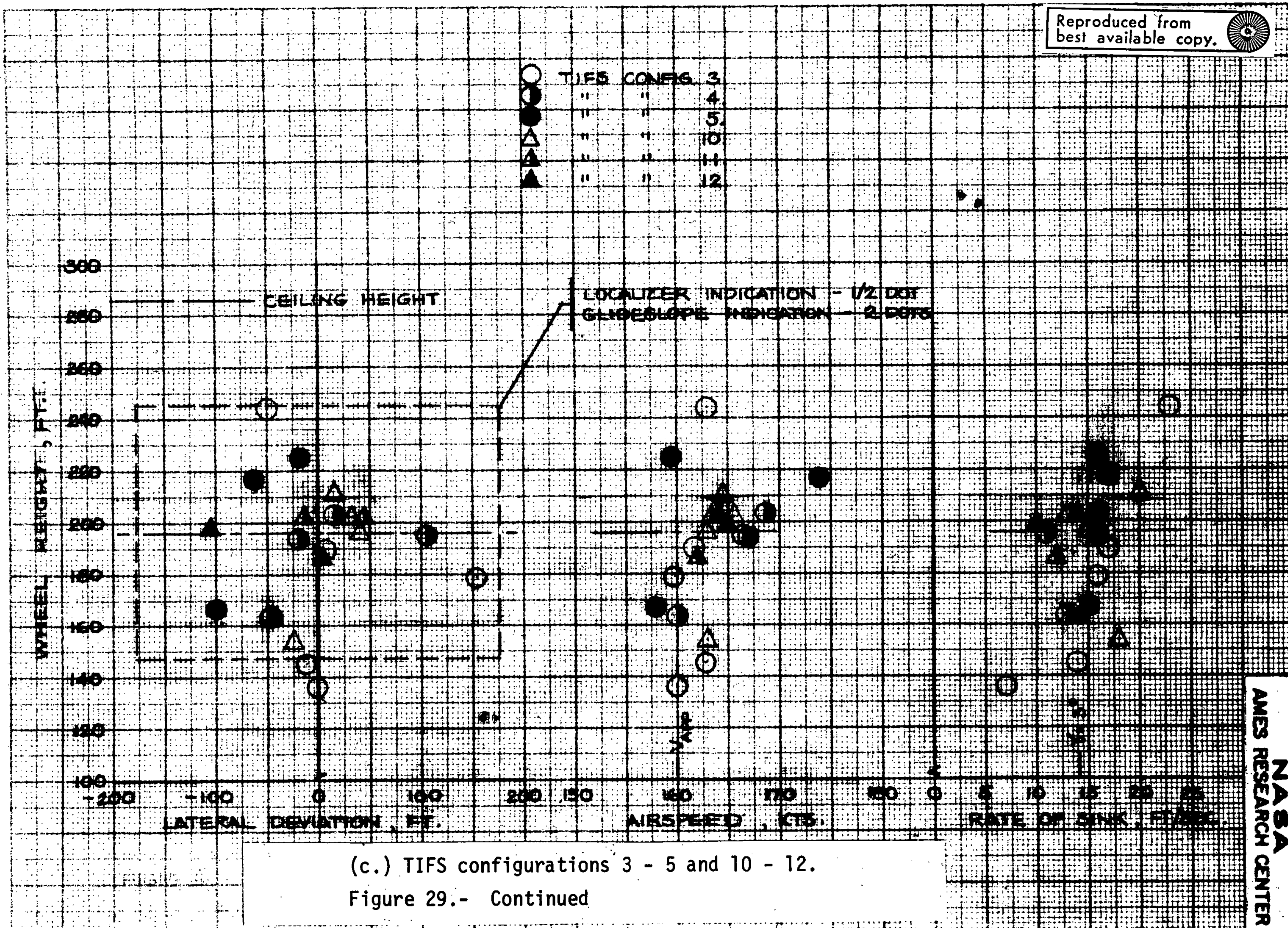
(a.) TIFS configurations 1 - 5.

Figure 29.- Flight-path tracking performance during Task B approaches; distance from runway threshold 3000 ft , glideslope at 3 deg.



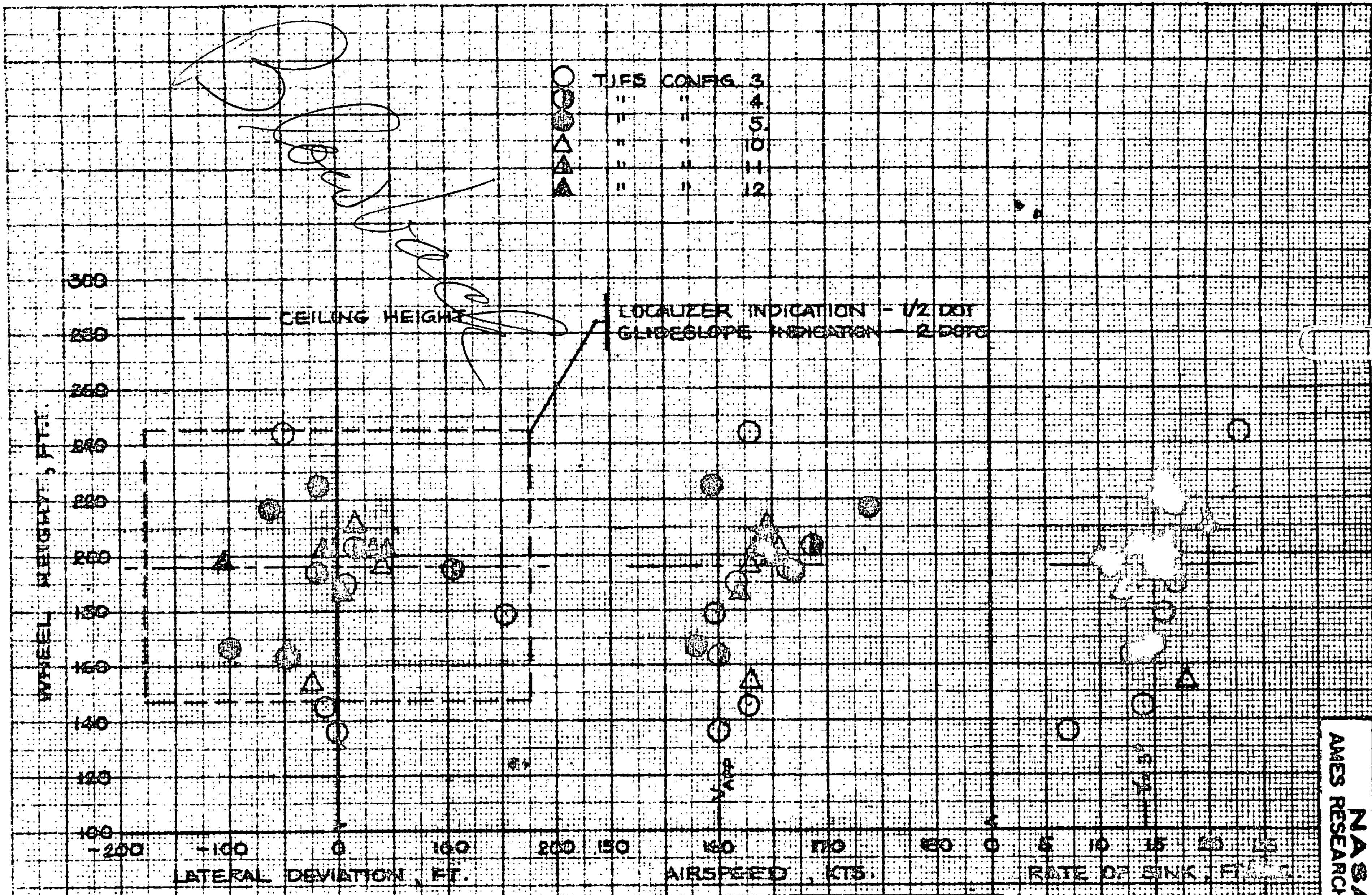
(b.) TIFS configurations 3, 6 and 8.

Figure 29.- Continued



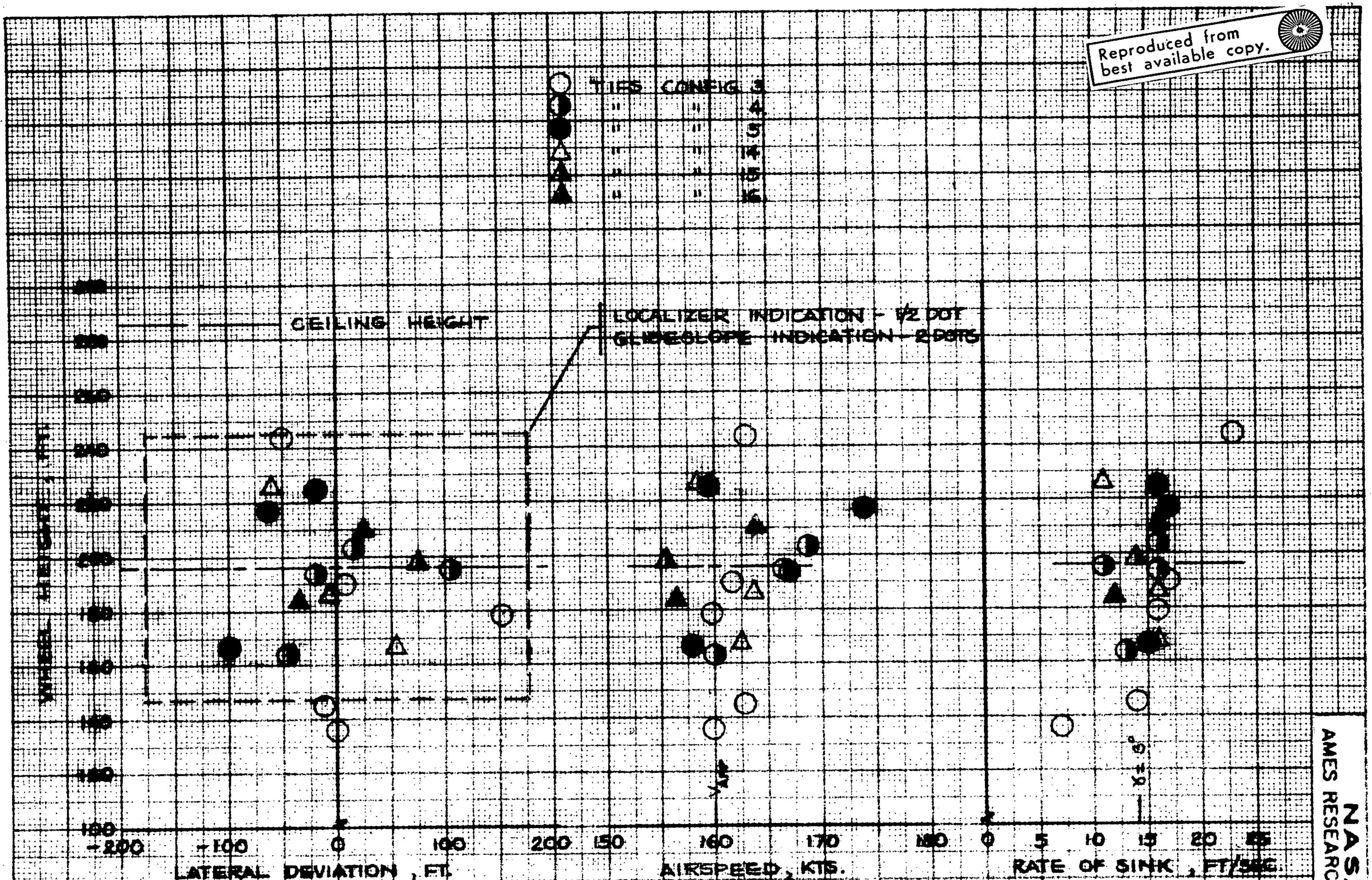
(c.) TIFS configurations 3 - 5 and 10 - 12.

Figure 29.- Continued



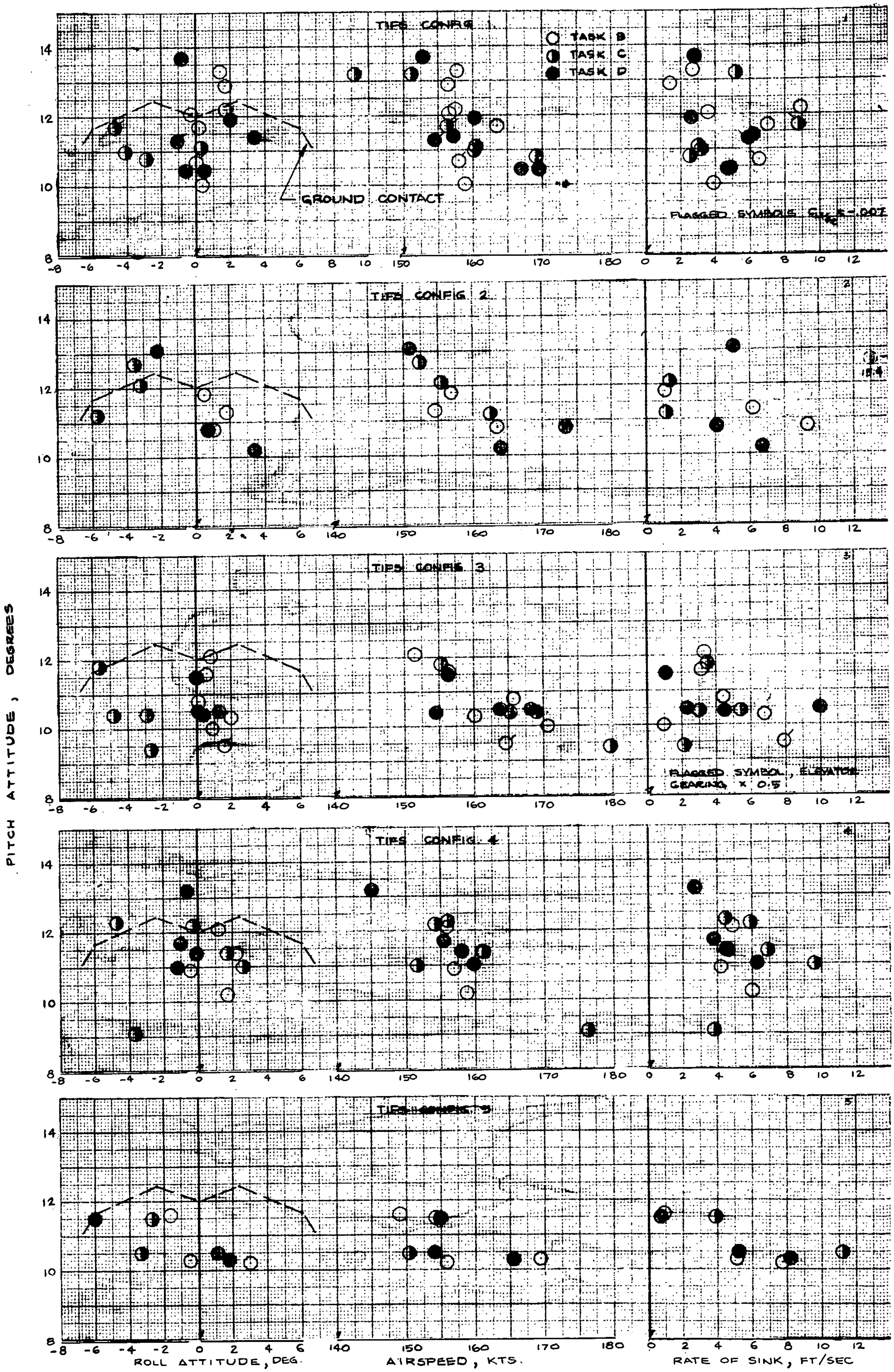
(c.) TIFS configurations 3 - 5 and 10 - 12.

Figure 29.- Continued



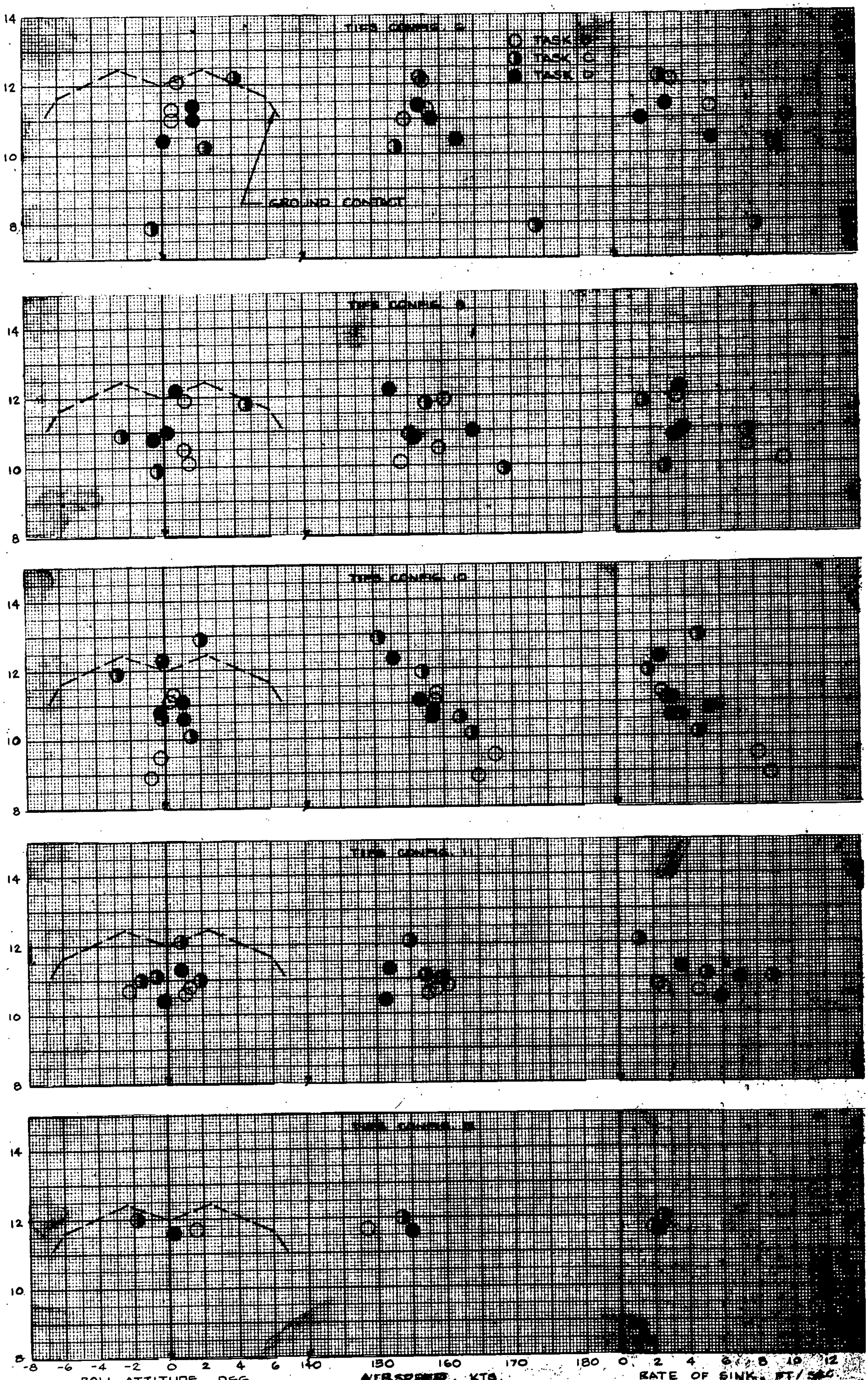
(d.) TIFS configurations 3 - 5 and 14 - 16.

Figure 29.- Concluded.



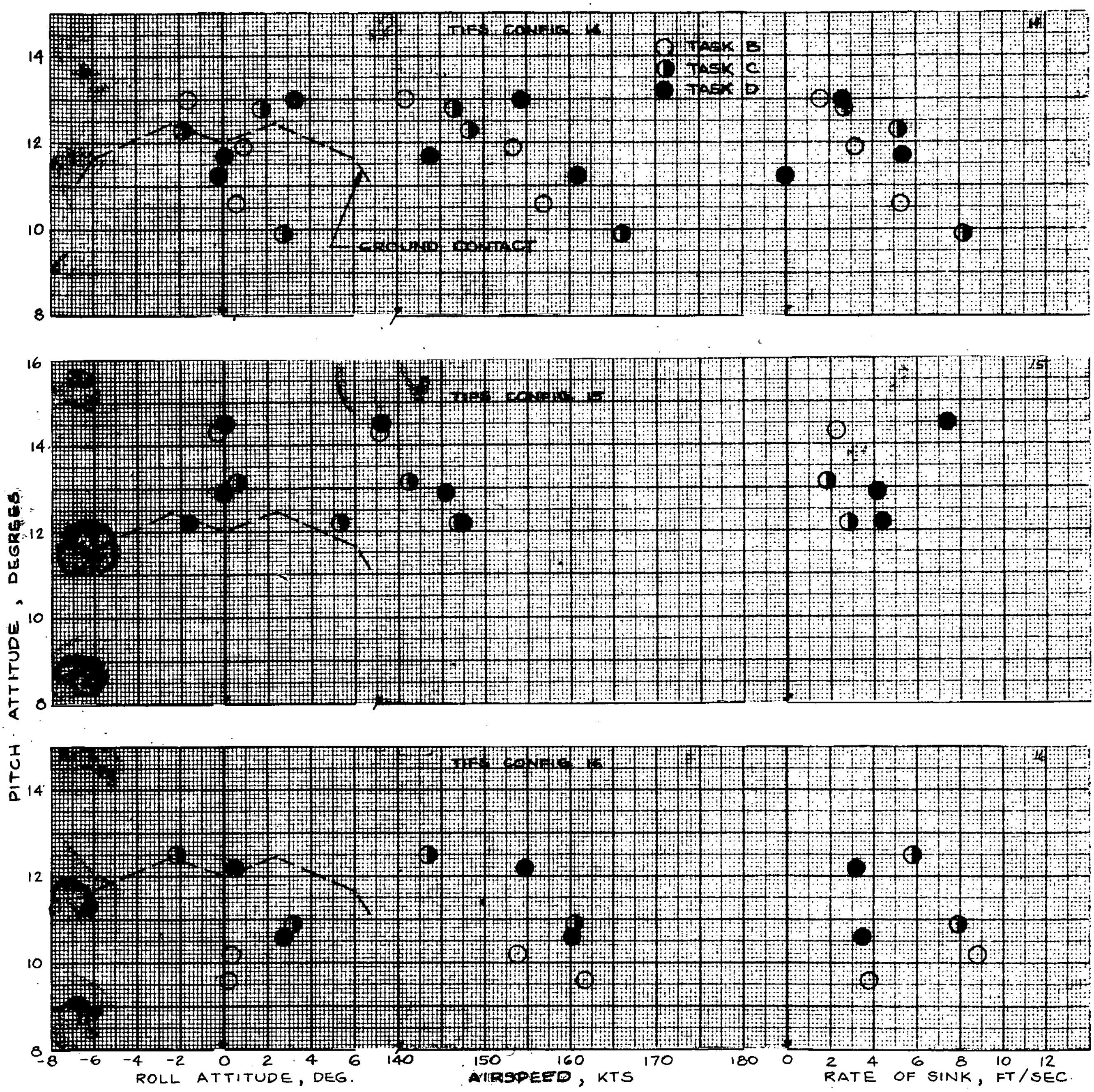
(a.) TIFS configurations 1 - 5.

Figure 30.- Roll attitude, airspeed and rate-of-sink versus pitch attitude at main gear touchdown.



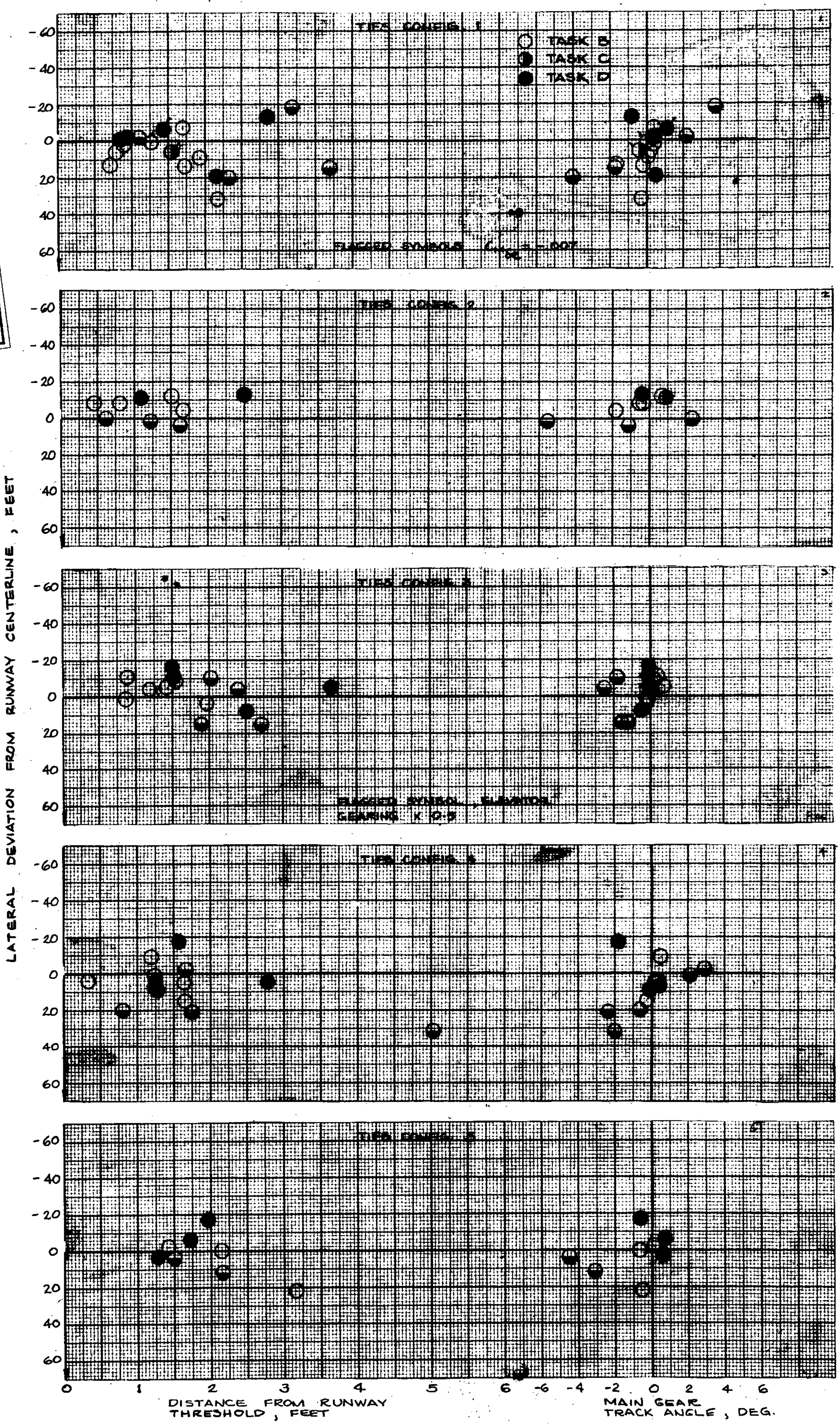
(b.) TIFS configurations 6, 8 and 10 - 12.

Figure 30.- Continued



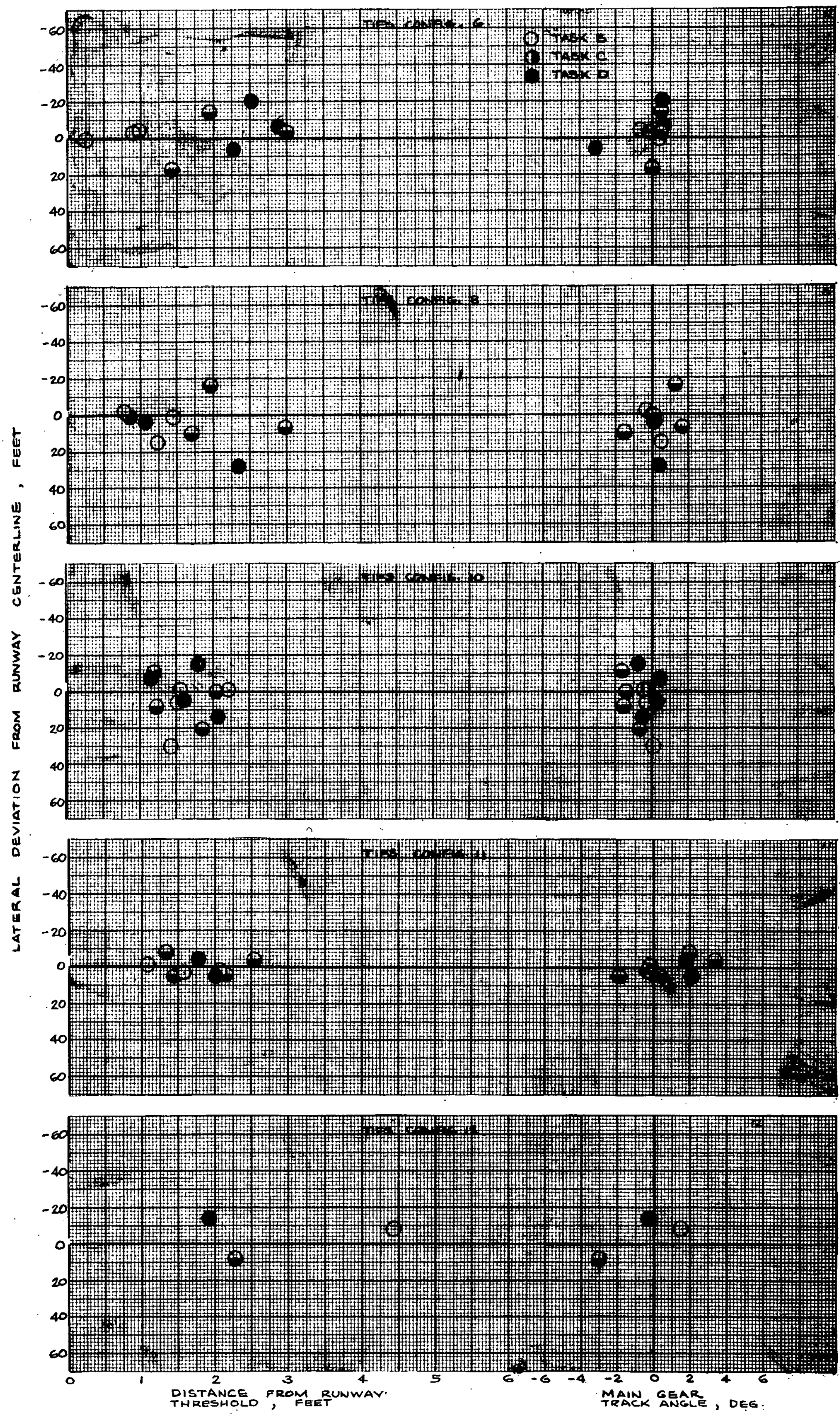
(c.) TIFS configurations 14 - 16.

Figure 30.- Concluded.



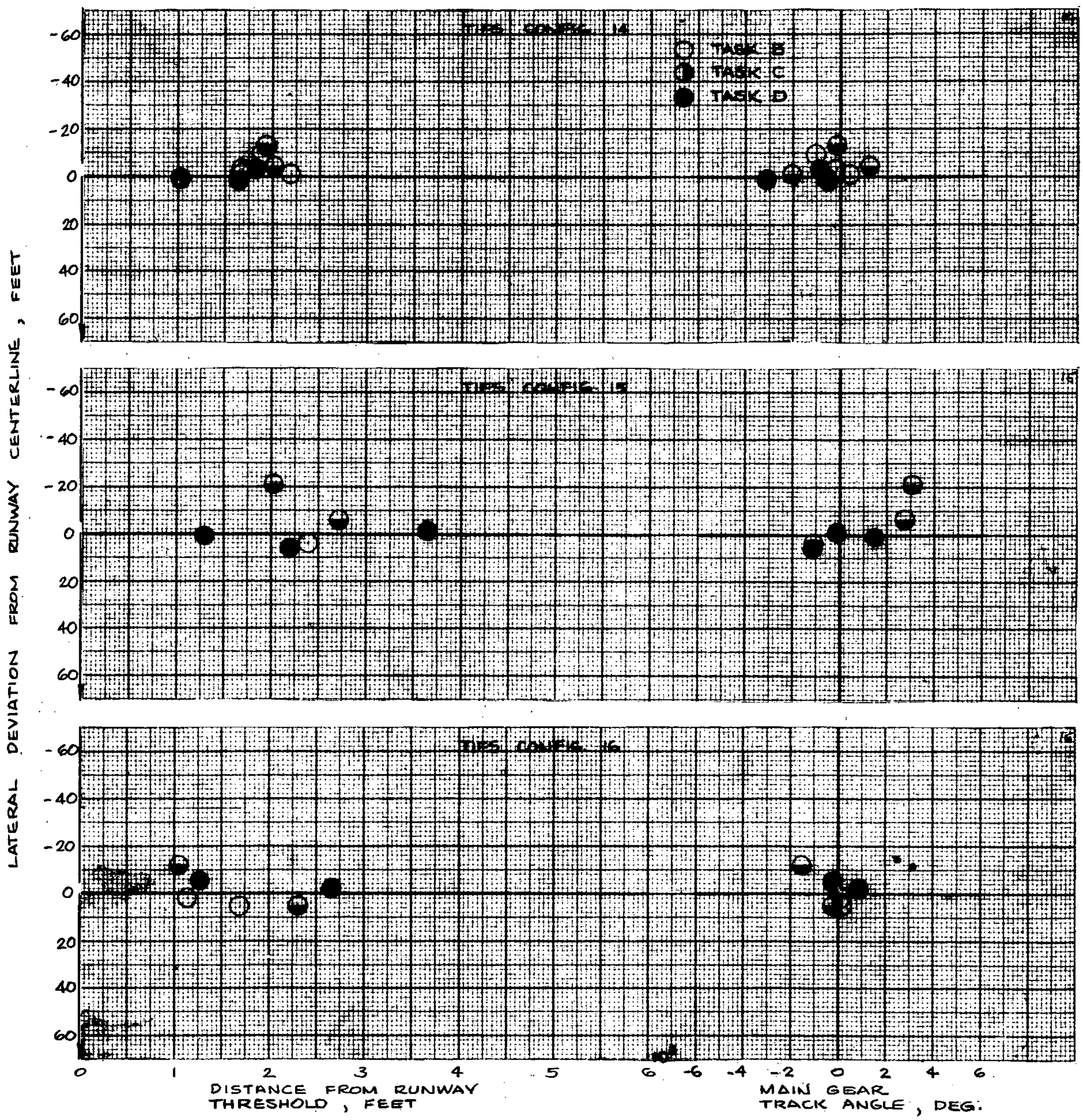
(a.) TIFS configurations 1 - 5.

Figure 31.- Distance from runway threshold and main gear track angle vs lateral deviation from runway centerline at main gear touchdown.



(b.) TIFS configurations 6, 8 and 10 - 12.

Figure 31.- Continued



(c.) TIFS configurations 14 - 16.

Figure 31.- Concluded.